A CAHNERS PUBLICATION INTERNATIONAL EDITION MAY 11, 1989

EDN®

Designer's guide to dynamic RAMs — Part 4

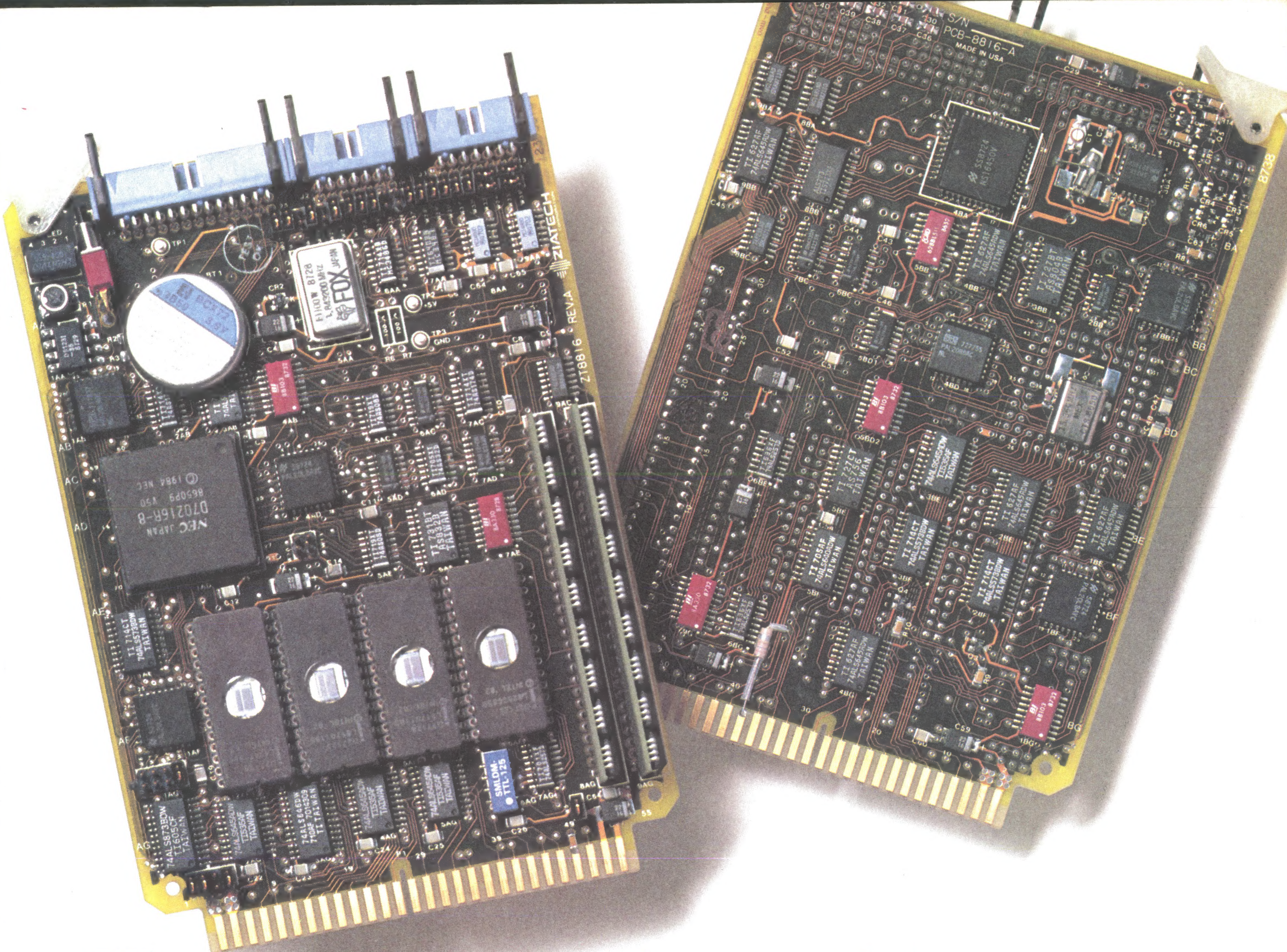
Rewritable optical drives solve mass-storage needs

Hall-effect sensors

PC-based oscilloscopes get high marks from EEs

ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS

New generation of op amps bring high speed and precision into the picture



WANT TO TALK SCSI? CALL CIPRICO AT 1-800-SCSI-NOW.

Why talk SCSI with Ciprico? To start with, we're the only vendor with a complete line of high-performance SCSI host bus adapters for Multibus® I, VMEbus, and Multibus II. Each board was designed to optimize performance with its system bus. And consider our experience. Ciprico has over 50,000 boards installed worldwide. Our design expertise provides you with the highest possible performance at the lowest possible price.

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Our SCSI adapters are all based on an 80186 microprocessor, providing a command queuing, pass-through SCSI command software interface. Each board supports SCSI disconnect/reconnect and asynchronous and synchronous transfer rates of 2MB/s and 5MB/s respectively. And a floppy port is optional for cost effective system design.

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If you were stranded on a desert island, this is the function generator you'd want.

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The Model 288 programmable function generator.

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CIRCLE NO 141

Volume 34, Number 10

EDN Magazine Edition

May 11, 1989

ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS

On the cover: *Many of the latest operational amplifiers combine high speed and precision. This improvement and others are due to new manufacturing processes and innovative circuit architectures. See pg 134. (Photo courtesy Analog Devices; photography by Jim Bashour)*

SPECIAL REPORT

DESIGN FEATURES

TECHNOLOGY UPDATE

Continued on page 7

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Continued from page 5

PRODUCT UPDATE

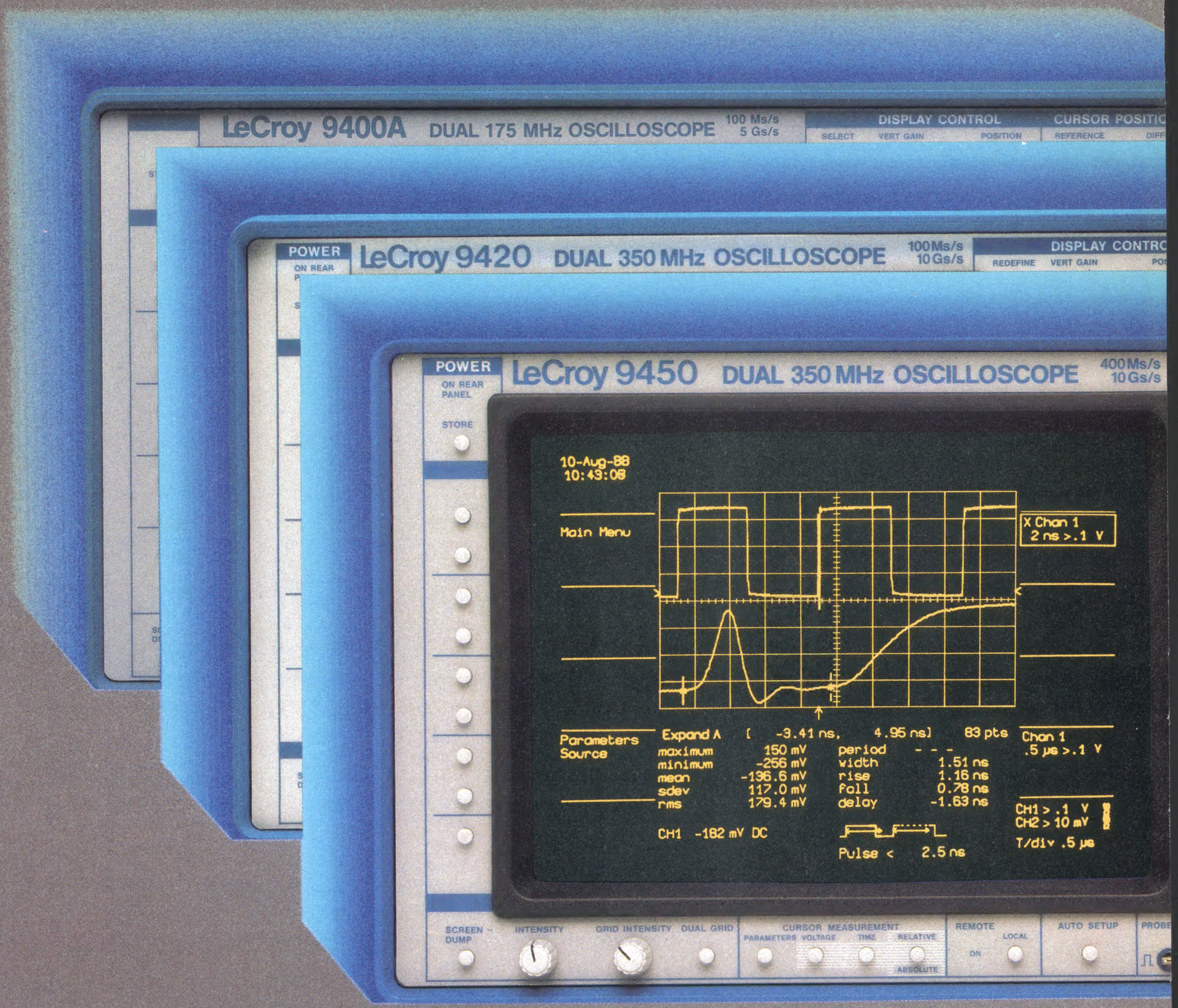
DESIGN IDEAS

NEW PRODUCTS

DEPARTMENTS

Cahners Publishing Company, A Division of Reed Publishing USA ☐ Specialized Business Magazines for Building & Construction ☐ Manufacturing ☐ Foodservice & Lodging ☐ Electronics & Computers ☐ Interior Design ☐ Printing ☐ Publishing ☐ Industrial Research & Technology ☐ Health Care ☐ and Entertainment. Specialized Consumer Magazines: ☐ American Baby ☐ and Modern Bride.

Who do the Best



Model	Bandwidth (MHz)	Sampling Rate S.S. (Ms/s)	RIS (Gs/s)	Memory per Channel (kwords)	Vertical Resolution (bits)	FFT Spectral Analysis
9450	350	400	10	50	8†	yes
9420	350	100	10	50	8†	yes
9400A	175	100	5	32	8†	yes

† up to 12 bits with averaging

Versatec drastic reductions on

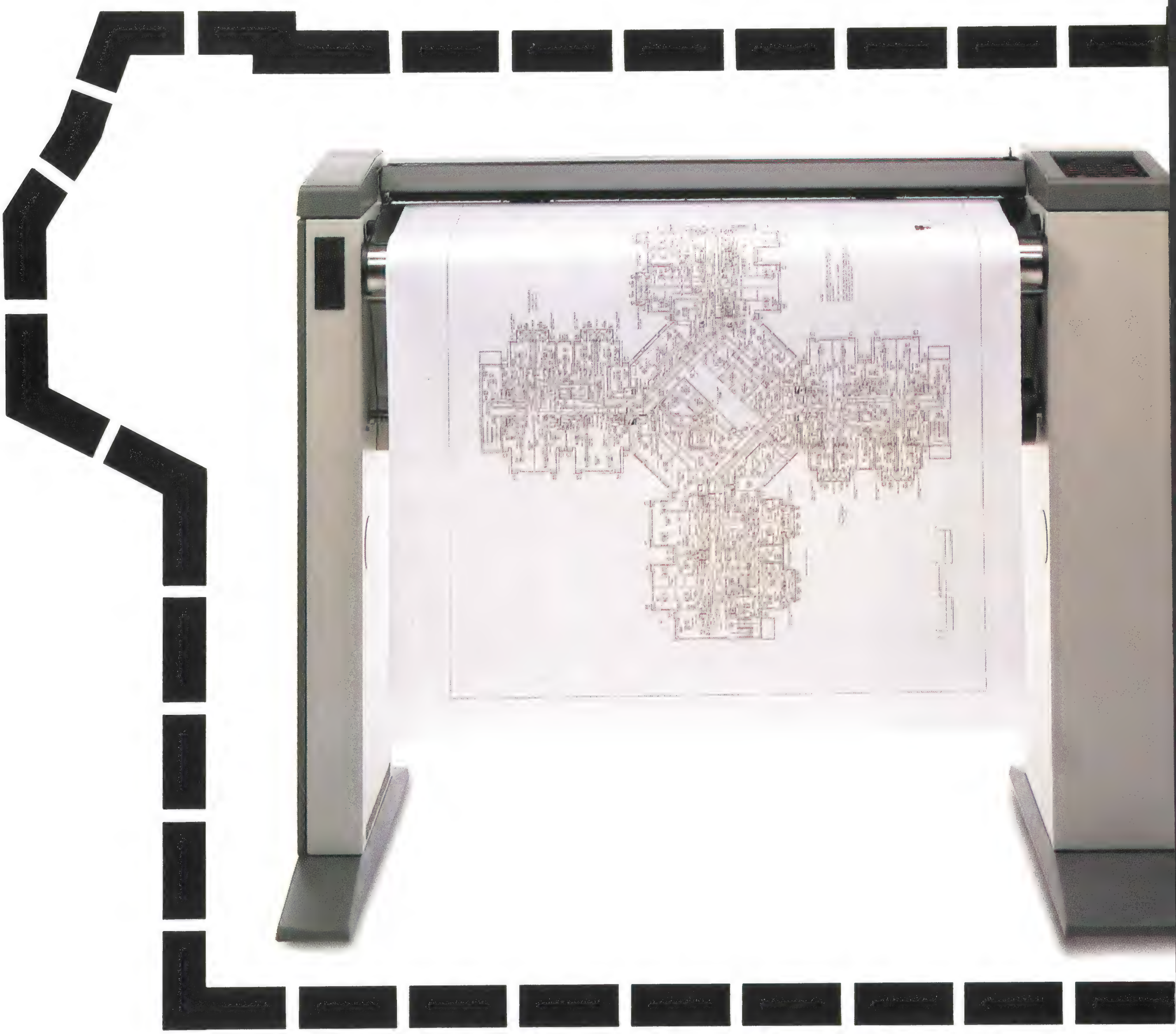
Introducing a plotter that's half the usual size and weight.

And half the price you'd expect to pay for electrostatic performance.

Yet our 8500 Series gives you all the quality you've come to expect from Versatec. The leader in electrostatic technology for over two decades.

And while squeezing down the size of our plotters, we managed to squeeze out a lot more performance. By teaming a lightning-fast 68020 32-bit microprocessor with a unique page buffer, data processing time is virtually eliminated, freeing your computer to do other tasks.

Reprints are a revelation too. You can generate up to 999 reprints without re-transmitting or re-rasterizing plot data. So your computer is



XEROX

announces electrostatic plotters.

freed-up immediately for other projects.

Also note that our transfer speed is the industry's fastest. 38.4K baud rate over a serial RS232C interface. And even faster with a Centronics interface. Compared to pen plotters, that means 6-20 times the throughput.

Now that's fast. But the 8500 Series is easy to handle as well. Media loading is up front. No more going behind the plotter to load.

Starting up is easy. You simply plug in the system and it's ready to plot. A unique user-friendly keypad takes anyone through the plotting process quickly, easily and in plain English. And a built-in micro-floppy drive saves even more time by storing plotter setups and interfacing configurations on-disk. Which means no more time-consuming setups.

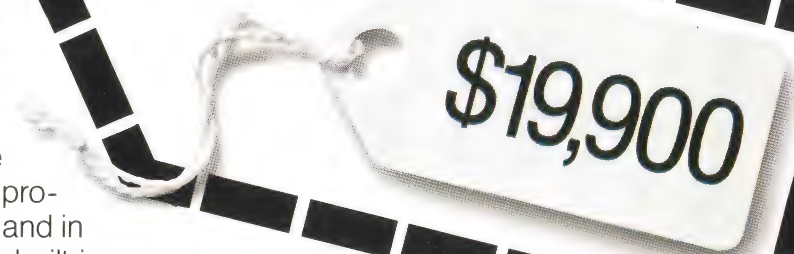
The 8500 Series is also the first plotter that's literally ready-to-roll.

Because its built-in casters let you move quickly to any location for sharing. You can also share through networking with a plot server. And at a quiet 55 db, the 8500 can work anywhere without disturbing anyone's concentration.

With optional features the 8500 also automatically cuts and winds plots. Up to 999 copies, overnight, completely unattended if you want. And it's available in both 400 and 200 ppi resolution, in either 24" or 36" formats.

You also get full support for 906/907 and HP-GL pen plotter data formats.

So designers have the freedom to use virtually any major CAD package they choose.



Incidentally, the same technology that reduces the size of the 8500 also makes it more reliable. Three to four times more so than the industry standard. Which means you'll have little need for our service personnel. Still, it's nice to know that we offer the most comprehensive service and support in the world. All over the world.

For more information on our 8500 Series, call our toll-free number now: (800) 538-6477; in California, (800) 341-6060.

But do it now. Because choosing any other electrostatic plotter could have drastic consequences for your budget.

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We deliver performance.

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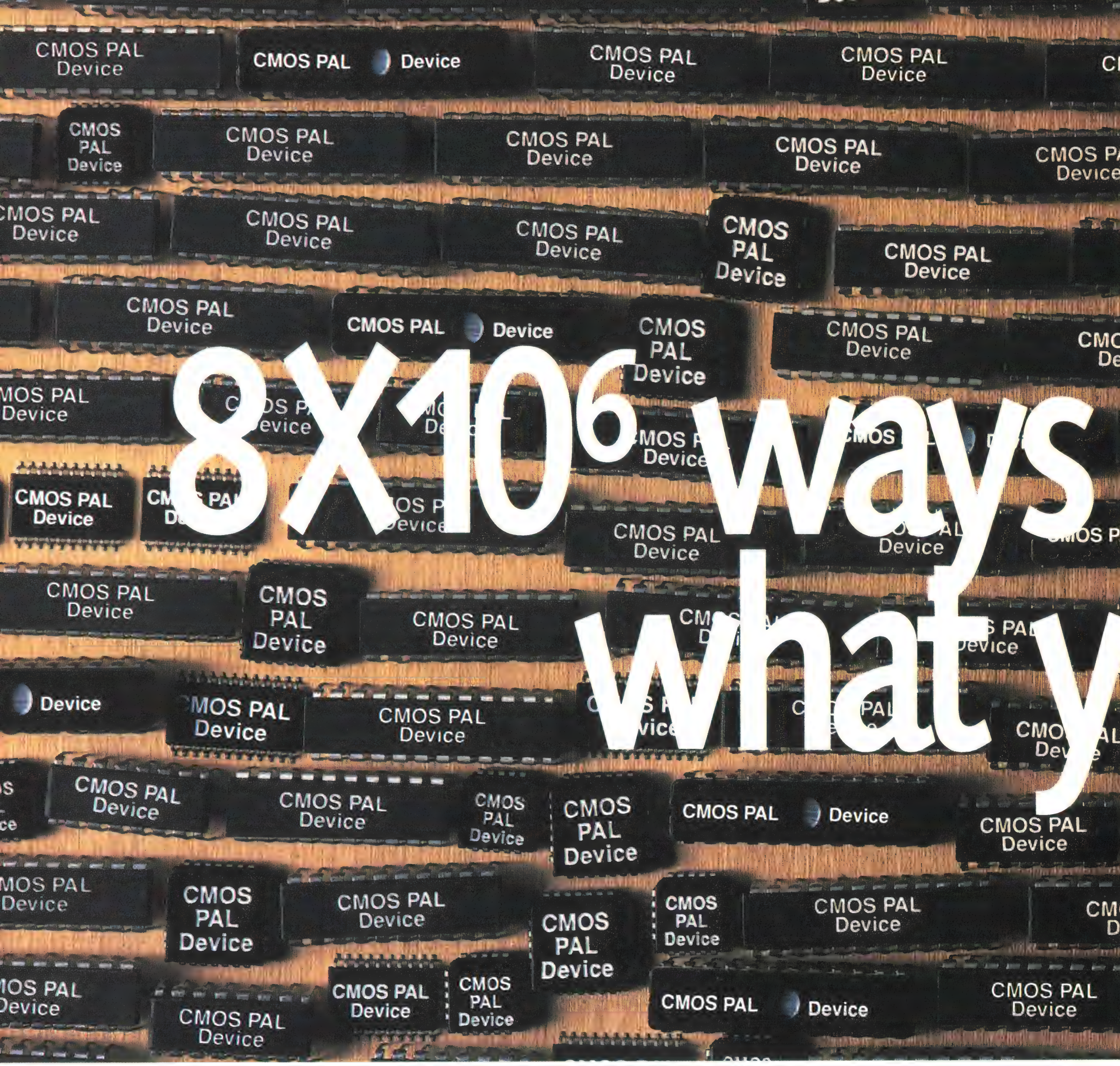
2710 Walsh Avenue, Santa Clara, CA 95051

CIRCLE NO 145



We have 8 CMOS PAL® chips. That totals up to 8 million different ways to program your logic. Quite enough of a choice to meet your most exacting low power logic needs. From universal PAL architectures to zero stand-by power PAL devices. You can have the system you want without compromise. And without costly delays.

Our all-purpose CMOS architectures give flexibility without draining precious power. The 24-pin industry standard PALC22V10 uses just 90mA—even when it's running at 25ns.

If you liked us in bipolar, you should see us in CMOS.

We have five CMOS ZPAL™ devices based on familiar bipolar architectures. You can use them in battery powered and low duty-cycle applications. And they use virtually no power when in stand-by. Two versions are electrically erasable. You can get the functions you're used to and you can change your design as fast as

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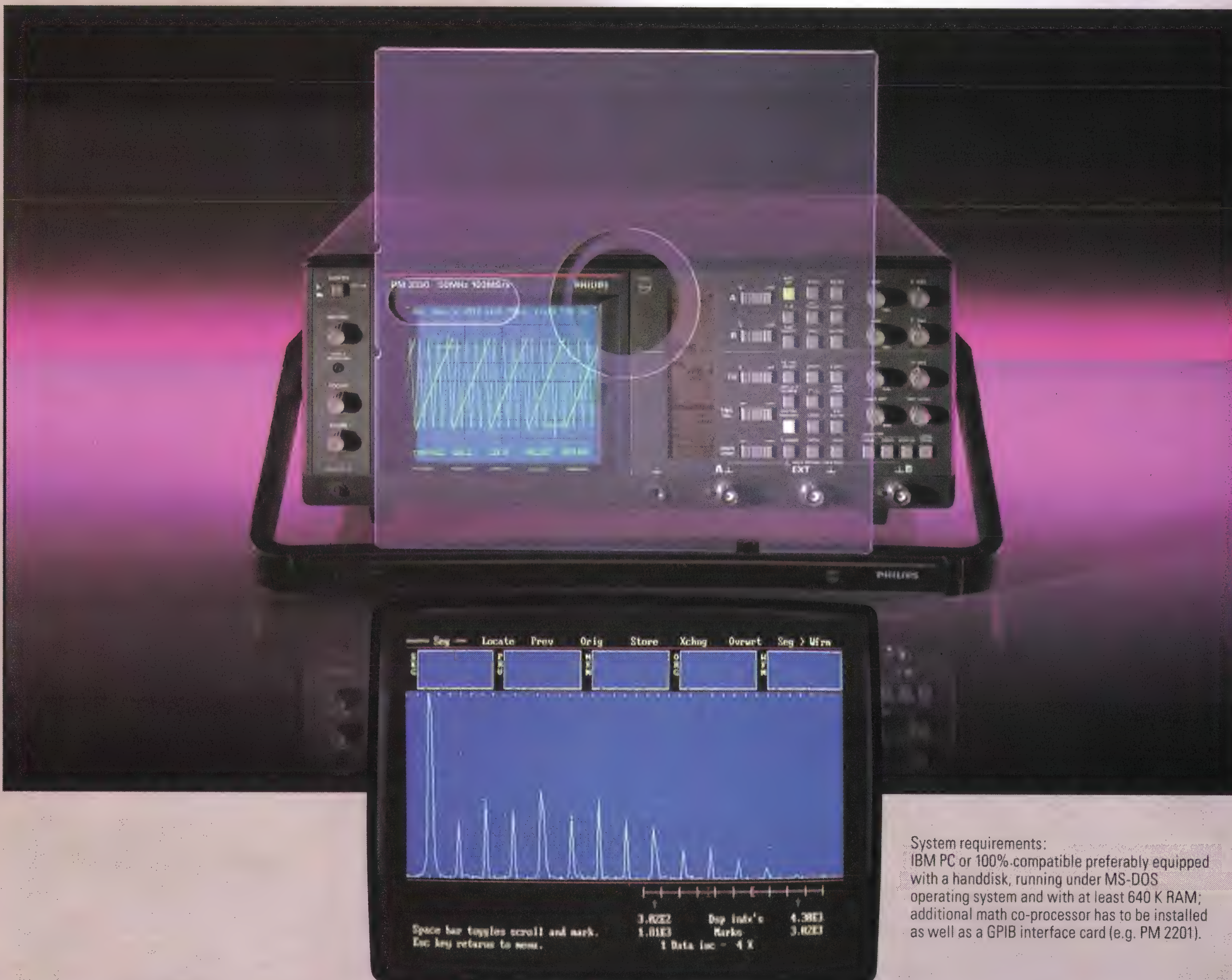

System requirements:
IBM PC or 100% compatible preferably equipped with a handdisk, running under MS-DOS operating system and with at least 640 K RAM; additional math co-processor has to be installed as well as a GPIB interface card (e.g. PM 2201).

UNPRECEDENTED DATA ANALYSIS FROM ANY PHILIPS DSO

Now, Philips offers you real data analysis power. With an unprecedented range of graphic and analytical functions. Plus instant display of the results.

All you need is a Philips digital storage oscilloscope, your personal computer and Philips' new ***PM 2260 software.*** *This package combines the ASYSTANT™ scientific software with specific Philips oscilloscope drivers. So you can transfer your acquired measurement data directly from oscilloscope to PC, and perform for example an FFT-calculation.*

Operation is fully menu-driven, with on-line help any time you need it. There's no need for any programming. You get full control of data presentation, with instant access to numerous high-level analytical and graphic functions (e.g. power spectrum, FFT, inverse FFT, auto and cross correlation, integration, differentation, axonometric and contour plotting as well as normal display of data).

The PM 2260 package is a powerful tool that lets you interact simply and visually with your data. Together with a Philips digital storage oscilloscope, it's the ideal way to get the most out of your measurements. Find out more from your Philips distributor of local sales organization.

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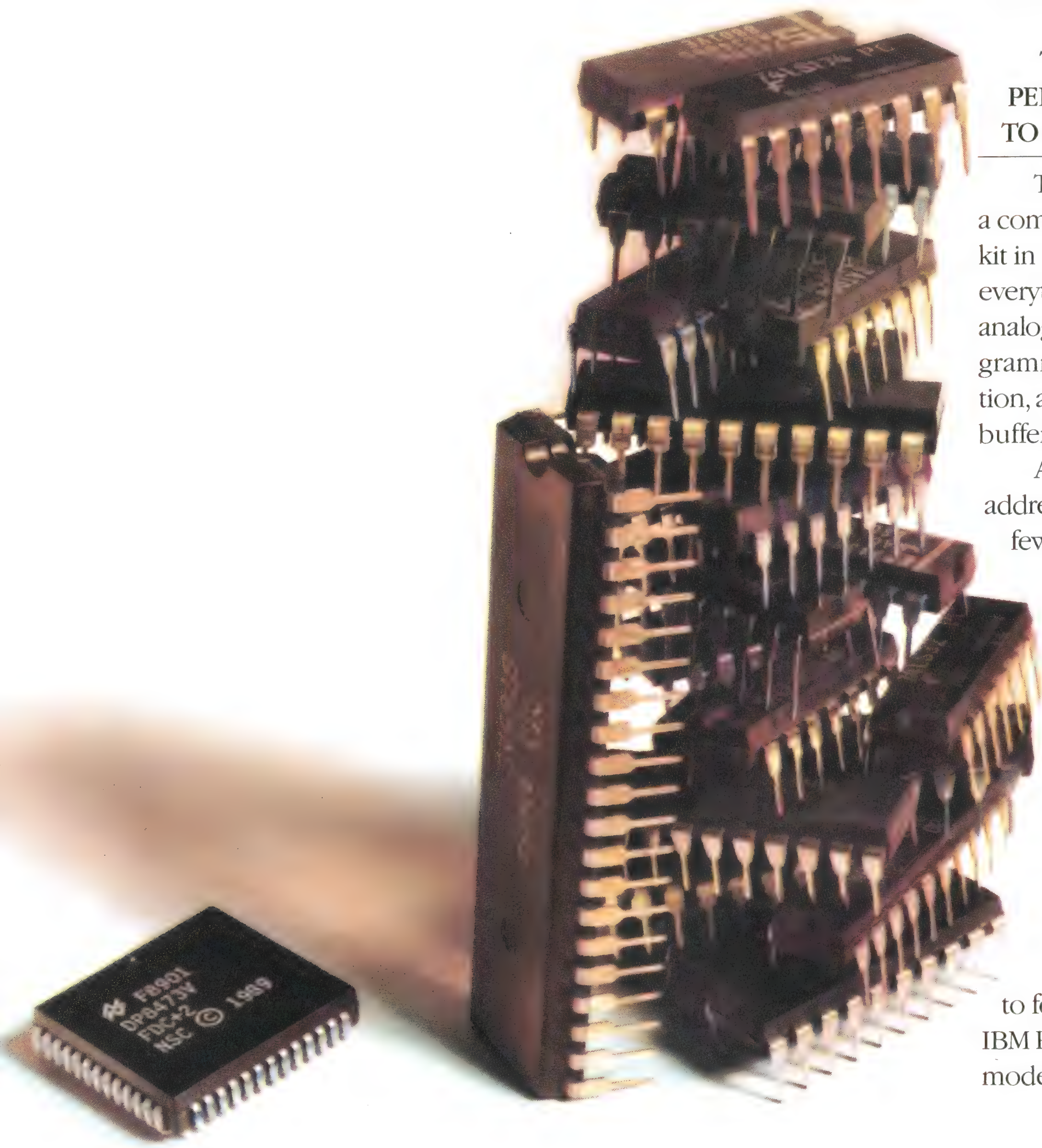


INTRODUCING
THE ONE-CHIP, HIGH-PERFORMANCE SOLUTION
TO FLOPPY-DISK CONTROL.

This new device is actually a complete floppy-disk controller kit in a single chip. It gives you everything you need—a precision analog data separator, pin-programmable write precompensation, and cable and bus interface buffers.

All you have to add is an address decoder, a crystal, and a few passive components.

Think of how quick and easy this kit will be to design with. The nitty-gritty work has already been done. And the DP8473 is fully compatible with the NEC μPD765A, the current industry standard. So all you have to do is drop it into your design. (And eliminate about 20 other chips.)

The DP8473 will control up to four floppy-disk drives in an IBM PC-XT,® PC-AT,® or any PS/2® model personal computer.

THE KIT.
National's one-chip solution to floppy-disk control.

AND THE CABOODLE.
Other solutions carry a lot of excess baggage.

the caboodle.
lot quicker without it.

QUICKER DESIGNS, QUICKER PROFITS.

In addition to your tremendous savings in real estate, your savings in raw components, inventory, and assembly could add up to more than $10 a board. So you not only get to market sooner, you also make a quicker profit.

Even more important, the DP8473 gives you better performance than any other integrated floppy-disk controller solution on the market.

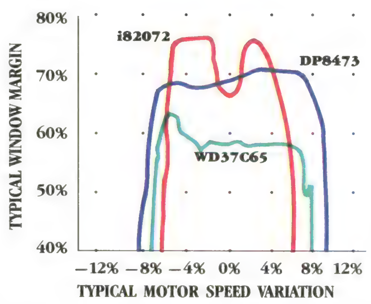
Unlike most competitors, its on-board data separator is analog rather than digital.

THE QUICKER WAY TO HIGH PERFORMANCE.

Because it has the continuous tracking ability of an analog phase-locked loop, the DP8473 is less sensitive to motor speed variation and bit shift. So it has a larger dynamic window margin.

In fact, its window margin is greater than any other integrated solution on the market — analog or digital. And, of course, the bigger your window margin, the better your data integrity. And the faster the data rates you can handle.

FLOPPY-DISK CONTROLLER PERFORMANCE



No other integrated data separator — analog or digital — can give you a 70 percent window margin at ±8 percent variation in motor speeds.

A QUICK PATH TO THE FUTURE.

The DP8473's analog data separator can handle transfer rates from 250k up to 1M bps. And disk drives with as many as 4,000 tracks.

You may not need that capacity right now, but the next generation of low-cost floppy-disk drives is already on the drawing table. And the DP8473 is ready to handle the data rates those drives will require.

It's also manufactured using low-power CMOS technology, so it's even ready for the next generation of battery-powered laptops. In fact, the DP8473 is the floppy-disk controller used in **Compaq's** new laptop computer, the SLT/286.

QUICK DELIVERY.

The DP8473 is in stock at your distributor now. So you can start taking advantage of its many benefits right away.

With the addition of this new floppy-disk controller, National's mass-storage chip set is now the most complete in the industry.

We can provide the ideal drive-control solution for every application — from PC to mainframe.

NATIONAL'S MASS STORAGE FAMILY

Floppy-Disk Data Controller
DP8473

Hard-Disk Data Controller
DP8466A

Data Synchronizers/Separators
DP8451 DP8455 DP8459
DP8461 DP8462 DP8465

Pulse Detectors
DP8464B DP8468B

2, 7 Encoder/Decoder
DP8463B

Async SCSI I/O
DP5380 DP8490

With data rates up to 25M bps. We also offer a complete line of hard-disk-drive support chips. For more information — quick — contact your National distributor. Or call us toll-free at 800-227-1817, ext. 17.

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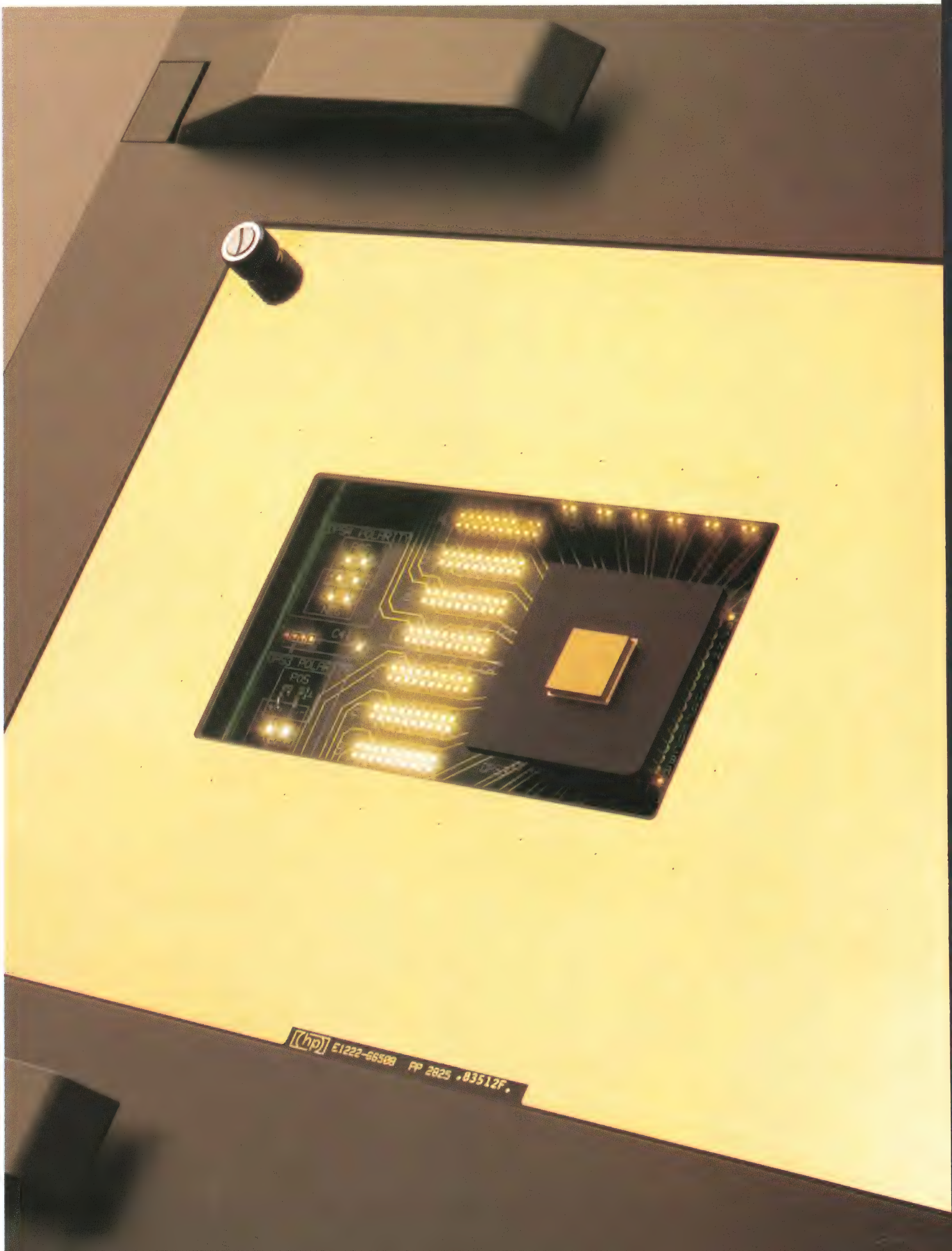
Now, evaluation systems dedicated to



faster ASIC turnaround.

Finally, a family of testers to cut ASIC development time ... the HP 82000 IC Evaluation Systems. Choose from high-performance or low-cost models. Both do prototype verification *and* IC characterization. They give you measures of confidence by making sure ASICs work right. Or showing you why if they don't.

Performance you weren't getting in verification systems.

Here's power to test fast, complex devices. Up to 200 MHz. 128 K vector depth. 384 true I/O channels. And ±250 ps accuracy. There's flexibility, too. True tester-per-pin architecture lets you define the parameters of each pin ... individually.

Simplicity that ATE systems can't match.

For fast setups, automatic test generation taps your EDA databases. You get characterization of designs automatically. High-resolution displays speed analysis. And X Windows make these the friendliest test systems ever.

Call **1-800-752-0900, ext. 215G,** today for details on the right model to speed your ASICs to market. And ask about HP systems for parametric process control, mixed-signal testing and parameter extraction too.

HEWLETT PACKARD

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"From here you've got two PLD choices. And they're both GAL® devices."

Fast, efficient state machines require the GAL22V10. A high-complexity machine with a large number of transition terms needs the GAL6001. Period.

When it comes to PLDs for state machines, trade-offs include speed, power and architectural flexibility. When speed is your most important criterion, turn to Lattice's GAL22V10. At 15 ns, it replaces the fastest industry-standard bipolar 22V10, but draws half the power.

High-complexity demands a different strategy. The 78 x 64 x 36 FPLA architecture, asynchronous clocking, and 38 logic macrocells of Lattice's GAL 6001 give you a combination of functional integration and flexibility that's unmatched in any other 24-pin package.

Behind these devices is the pioneering E²CMOS™ technology invented by Lattice. Thanks to this technology, our GAL devices give you speed/power performance superior to any other PLD.

Lattice GAL devices also reduce your cost of ownership because of their 100 percent testability. Every characteristic is tested on every part. Repeatedly. So functionality, programmability and AC/DC performance are fully guaranteed.

The right PLD strategy can be the difference between winning and losing the whole ballgame. Period. And that leaves only two choices. The GAL22V10. And the GAL6001. Only from Lattice.

Lattice Semiconductor Corporation™

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Inventors of the E²CMOS PLD℠

Circle 92 for Literature

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NEWS BREAKS

EDITED BY JOANNE DE OLIVEIRA

FAST BUFFERS DRIVE 1A INTO 10Ω LOADS

Elantec Inc (Milpitas, CA, (408) 945-1323) now offers two powerful and fast buffer amplifiers based on a dielectrically isolated process. The monolithic EL2008 and EL2009 can each supply 1A of continuous output current. They feature bandwidths of 55 MHz and 90 MHz while driving 10Ω loads. Under these loads, they can buffer signals with slew rates of 3000V/μsec. When the buffers drive 100Ω and 50Ω loads, respectively, the bandwidths of the 2008 and 2009 increase to 100 MHz and 125 MHz. The 2008 and 2009 draw 13 mA and 45 mA of quiescent current, respectively. The output impedance of each device is 1Ω. Each device features a thermal-shutdown circuit that senses the device's junction temperature and, when necessary, disables the output stage to maintain a safe operating temperature. The amplifiers also feature short-circuit protection against dc fault conditions and excessive ac current into reactive loads. Each buffer comes in a 5-pin TO-220 package; the heat-sink metal tab is insulated from the die, so that you can mount the tab to an external heat sink or chassis without an insulator. The buffers operate over the industrial temperature range (−25 to +85°C) and cost $12.50 (100).—Anne Watson Swager

SOFTWARE TESTS PLDs WITHOUT PRELOADING

PLD Test Plus from Data I/O Corp (Redmond, WA, (206) 881-6444, FAX 206-882-1043) isn't the first software to generate PLD test-vector sets that you can run on registered PLDs without initializing (preloading) the devices, but it is the first such package from a major vendor. The ability to test PLDs without preloading is important because many high-speed devices don't allow preloading at all. Preloading some other PLDs requires application of higher-than-normal voltages to specified pins. If you attempt to test such PLDs in circuit, the high voltage can prove fatal to ICs connected to the device under test. In addition to generating vector sets that maximize fault coverage while using a minimum number of vectors, the new software addresses the needs of both design and test engineers. For example, it determines the degree of fault coverage achieved by vector sets developed by logic designers. There are two versions of the software: One runs under MS-DOS 3.1 or higher and sells for $5995. (Users of the vendor's older PLD Test package can upgrade to PLD Test Plus for $2000.) The other version runs under SunOS 3.5 or higher and sells for $9600.—Dan Strassberg

MODULAR CAE PACKAGE LETS YOU CHOOSE YOUR WEAPONS

The Explorer Series is a modular suite of IC-design tools that lets you customize your CAE software system to suit your particular design methodology. The Explorer Series, from Silicon Compiler Systems (San Jose, CA, (408) 371-2900), has three main components. The first is Foundation, a user-extensible design framework that allows you to build or extend your IC-design system, integrating all aspects of design tools from any vendor with a consistent user interface and a unified database. Explorer Tools, the second component, is a set of 15 modular design tools that you can integrate either wholly or in pieces, within Foundation or as stand-alone tools with other CAE packages in your design arsenal. The tools offer capture, synthesis, simulation, analysis, test, and other capabilities.

The third component is Explorer Design Systems, which comprises six comprehensive packages that are optimized for particular applications. With Composite Designer, for example, you can create IC layouts of handcrafted quality; ASIC Designer gives you the flexibility to explore design tradeoffs among gate-array, standard-cell, and fully custom circuit implementations. IC Designer supports all physical-design methodologies, from manual polygon-level design through symbolic, procedural, and automated design methods. Foundation starts at $25,000, depending on the software configuration; the Explorer Tools range from $10,000 for Explorer Schematic to $49,500 for the Explorer L-Sim simulator. Explorer Design Systems range from $35,000 for CAECO Designer to $135,000 for IC Designer.—Michael C Markowitz

OVER-THE-CELL ROUTING TECHNOLOGY SHRINKS IC DESIGNS

Automatic over-the-cell routing technology, an integral part of the automatic-place and -route tool set of Cell Station/Blocks from Mentor Graphics (Beaverton, OR, (503) 626-7000) can shrink the size of cell- and block-based IC designs by 25%, the vendor claims. The automatic over-the-cell routing technique uses space ignored by other routing systems and provides densities approaching those of handcrafted designs without the design-time penalty. The product, including the workstation, costs $66,900 for an Apollo Series 3000 and $204,900 for an Apollo Series 10000.
—Doug Conner

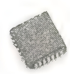
ADVANCED GRAPHICS PERIPHERALS SUIT CAD/CAE APPLICATIONS

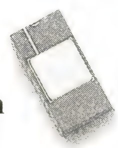
Compaq Computer Corp (Houston, TX, (713) 370-0670) now offers a $1499 Advanced Graphics 1024 Board and $1999 16-in. color monitor for any of Compaq's desktop personal computers. Together, these peripherals provide greater screen resolution than the VGA standard and offer as much as five times the performance level of IBM's 8514 graphics system. The 34010-based 1024 Board provides 1024×768-pixel resolution and displays 16 colors from a 16.7-million-color palette. If you add the optional Advanced Graphics Memory Board ($599), your computer will be able to display 256 colors simultaneously at the same resolution.—J D Mosley

PERSONAL-COMPUTER-BASED-CAE VENDOR ADDS PLD SUPPORT

You can now buy Tango-PLD software from Accel Technologies (San Diego, CA, (619) 695-2000) to go along with the company's Tango-PCB, -Route, and -Schematic personal-computer-based CAE programs. The $895 PLD package allows you to use a C-like language to describe logic designs and generate test vectors. Furthermore, you can generate the logic design independently of choosing a specific PLD. The program also accepts logic descriptions in the form of Boolean expressions, truth tables, state machines, schematic net lists, and JEDEC files. The company will begin shipments of the product during the second quarter.—Maury Wright

Stay Generations Ahead in Video/RF 12-Bit ADCs





When it comes to the industry's highest performance 12-bit, 10 MSPS converters, TRW LSI can keep you out front. Whatever your data acquisition problem, TRW LSI's THC1200 Series provides the solution.

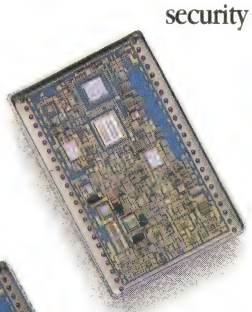
Take the THC1201: It's completely self-contained, including track/hold and all timing circuitry. Signal in, data out, all in a 46-pin hermetic DIP. Standard ±1.0V input range, ±15V and ±5V supplies, TTL interface and synchronous data output make this the easiest part of your system design.

Really cramped for space? Try the THC1202. You get the same leading-edge performance as the THC1201, but in a 40-pin package that's 40% smaller. And, as an extra bonus, you can dump that -15V power supply. And accommodate bipolar or unipolar input signals. That's not all . . .

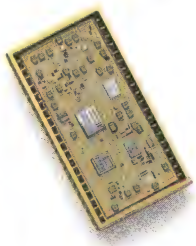
If you have signals down in the mud, our THC1200 is the solution. It offers a full scale input range of ± 167 millivolts. That means you won't need that extra low-noise gain stage. But, the whole world doesn't speak softly, so the THC1200 has a gain switch that gives you a ±2.5V input range. That's a gain shift of 15X, extending the dynamic range by over 23dB.

Need more? Give us a call. We have many other leading-edge conversion products on the drawing board. Or we'll do one just for you.

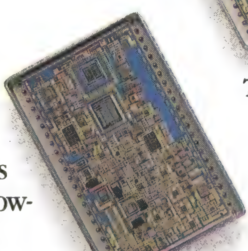
Even if you have already solved your 12-bit acquisition problem, talk to us. Remember, we guarantee full-spec performance. Plus, we can show you how to save time, space, power and money — and obtain multiple-source security without a redesign.



THC1200

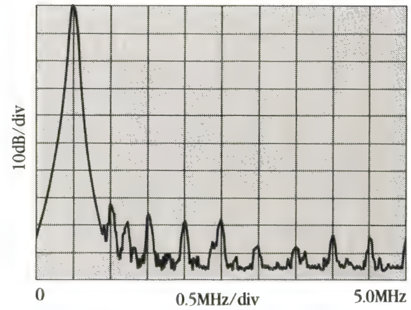


THC1202



THC1201

TRW LSI Products — Bringing the worlds of Data Acquisition and DSP together to keep you generations ahead.



Part Number	Analog Input Range (V)	Package Style	Area (Sq. In.)	Power (W)
THC1202	±1.0	40-Pin DIP	2.3	5
THC1201	±1.0	46-Pin DIP	3.8	5
THC1200	±2.5 and ±0.167	46-Pin DIP	3.8	9

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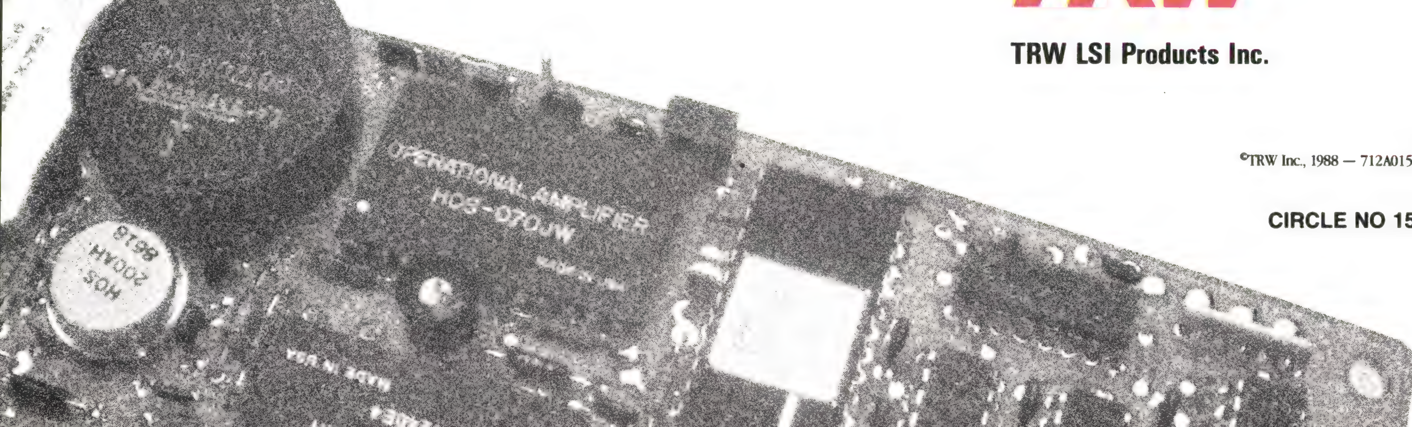


CIRCLE NO 150

INTERNATIONAL GROUP WILL GOVERN SPARC μP STANDARDS

A new nonprofit industry group will now ensure that all companies have equal and open access to the hardware and software products and technologies needed to build computer systems based on the SPARC μP architecture. The SPARC International group (Mountain View, CA, (415) 966-8718) has yet to find a permanent home, but it already has a detailed agenda and a charter. The group has an agreement with Sun Microsystems Inc (Mountain View, CA), Phoenix Technologies Ltd (Norwood, MA), and Interactive Systems Corp (Santa Monica, CA) to direct the open licensing of the Sun operating system (SunOS) and software-development tools for SPARC processors. The tools include C and Fortran compilers as well as Sun's network software (ONC/NFS), and SunView and OpenWindows programs. The SPARC International group will also work with AT&T's Unix Software Operation (Morristown, NJ) to jointly develop the Unix System V release 4.0 Applications Binary Interface (ABI) for the SPARC architecture. SPARC International's activities also include hardware. The group will direct the future developments and extensions of the SPARC architecture.—Jon Titus

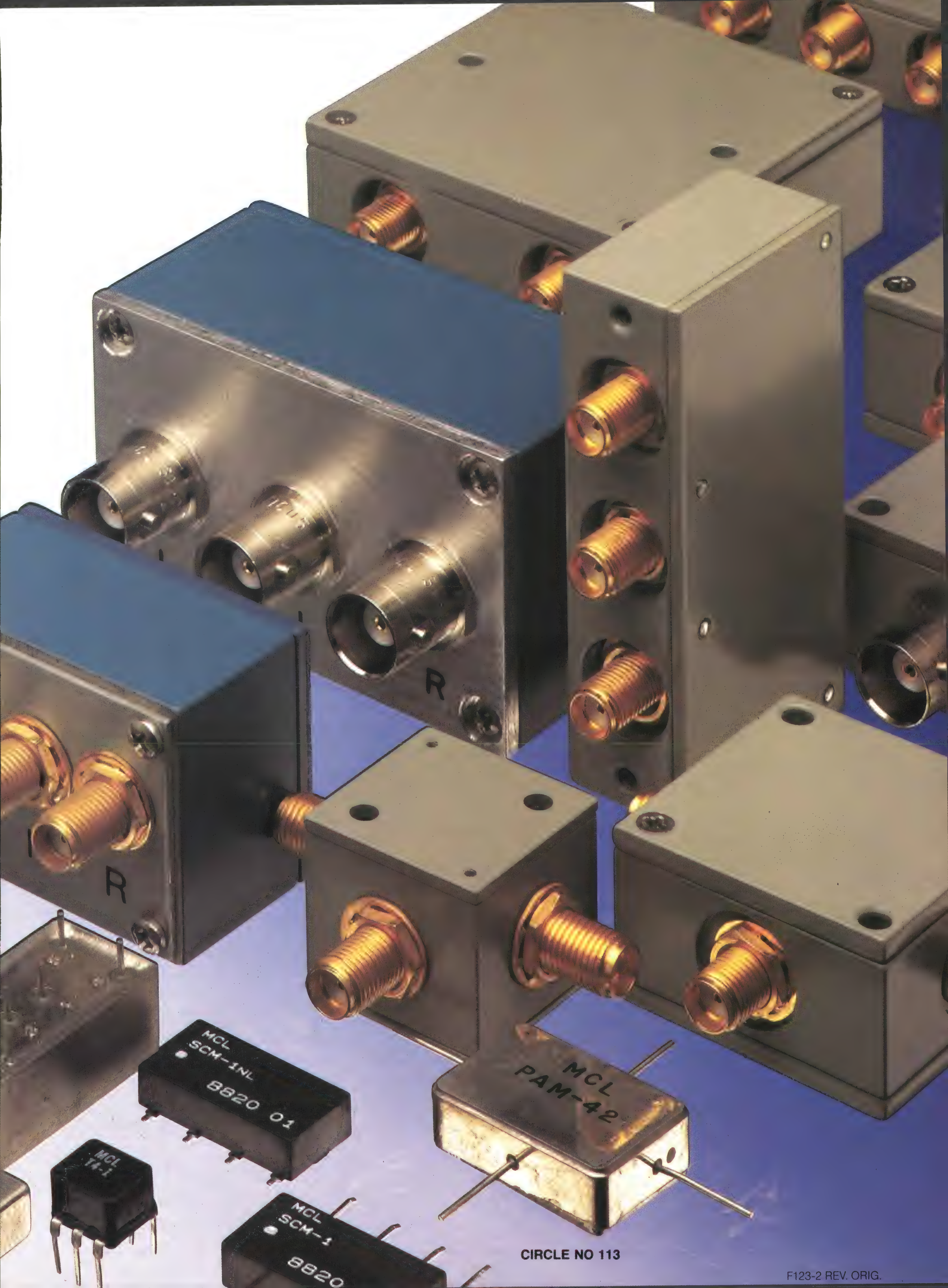
CLOCK ADAPTER EASES T1-CEPT TRANSLATION

Level One Communications (Folsom, CA, (916) 985-3670) has introduced a single 8-pin IC solution to the problem of synchronizing clock rates between the North American T1 and European CEPT telephone lines. The LXP600 clock-rate adapter (CLAD) accepts either a 1.544- or a 2.048-MHz clock signal as an input signal and generates the other as an output signal along with an 8-kHz frame sync pulse. The output signal has the same accuracy as the input clock and has output jitter of 15 nsec. The LXP600 costs $12.25 (100).—Richard A Quinnell

SOFTWARE PROVIDES PROCESS-CONTROL PC/AT MIMIC DIAGRAMS

Targeting systems integrators and VARs, the Mimic software package from Computer Solutions Ltd (Byfleet, UK, TLX 94012915) allows you to use an IBM PC/AT or compatible computer as a process-control computer with on-screen interactive mimic diagrams. The software lets you create mimic diagrams from libraries of standard mimic elements or from user-defined elements, and produces a database that defines the sensors associated with each mimic element, together with their limit values. It then allows you to program process-control sequences and the way in which process parameters are displayed on the mimic diagrams. As many as four separate control sequences can be executed simultaneously, and each sequence can include conditional branching and interactive operator control. You can also arrange for sequences to execute at predetermined times. The software can accommodate data-acquisition and -control cards that plug into the PC/AT bus, as well as instrumentation that is accessed via serial ports. Although you have to write drivers for the I/O devices yourself, Mimic provides you with all the hooks required to integrate these drivers into your applications program. The package also generates full documentation for the system. The license charge for Mimic (to volume users) is $85 per copy.—Peter Harold

CIRCLE NO. 151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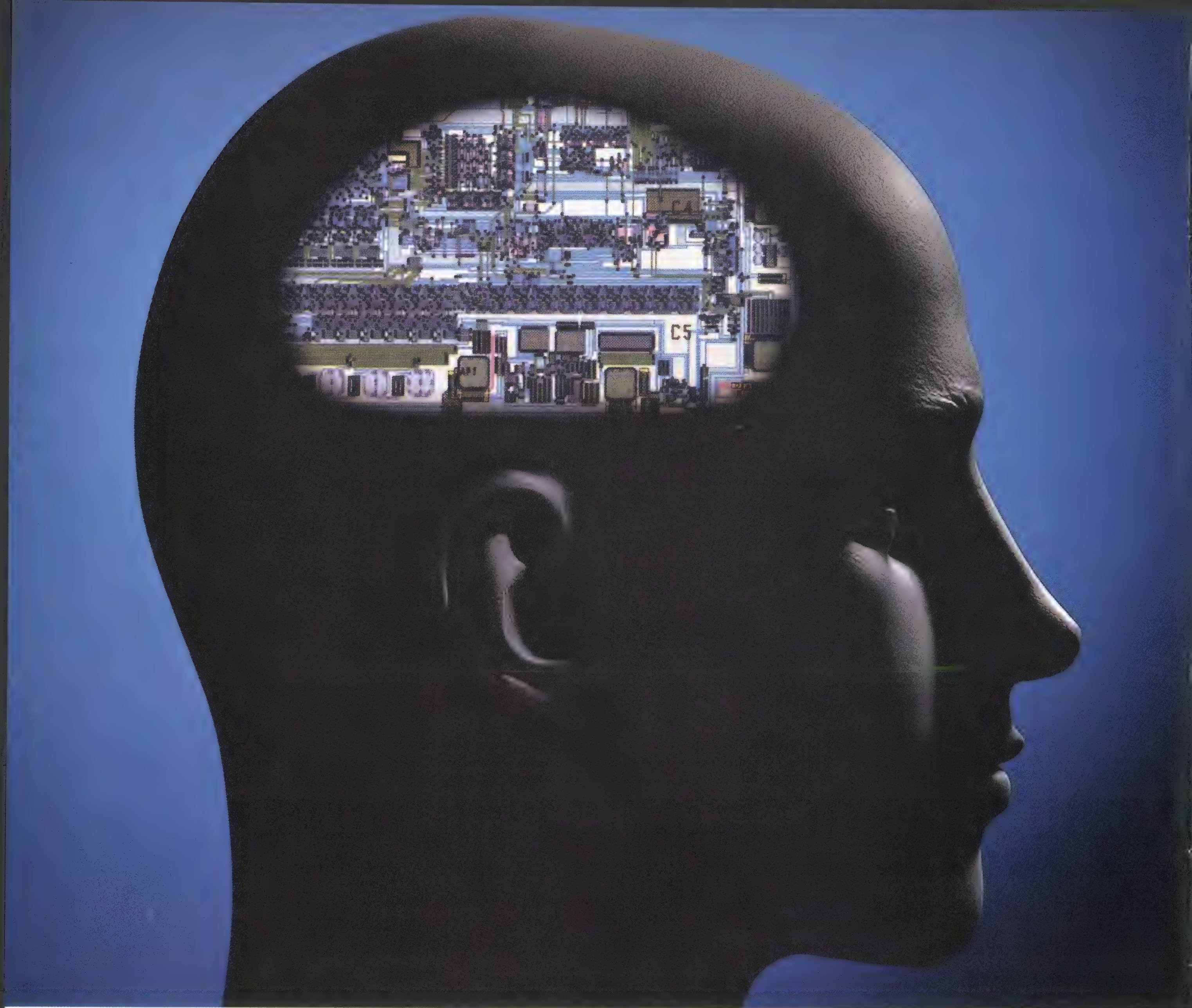
PAM-42



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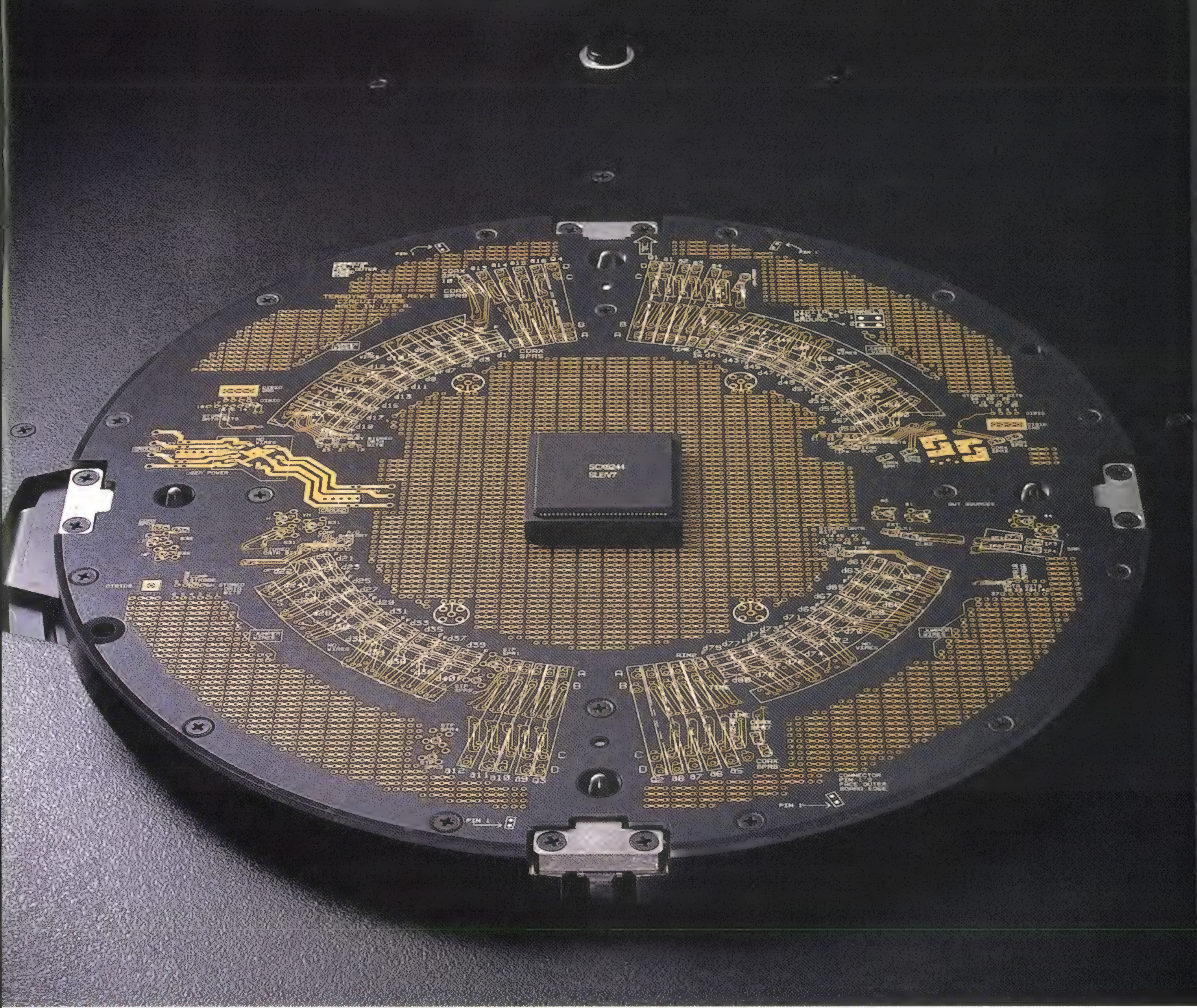
Teradyne has taken its revolutionary A500 architecture and created two new, compatible systems. The A510, a workstation-based standard linear tester, with the lowest cost



Real-time-system software design can be hard

This is a quick response to Jon Titus's editorial in EDN's November 24, 1988, issue (pg 51), in which he presents the views of Brady Barnes on the relative difficulties of hardware and software development.

For the most part, I agree with Brady Barnes's sentiments and understand very well the viewpoint from which they come. Hardware development in a competitive enviroment with an ever-increasing spectrum of new parts to keep up on is, for me personally, more taxing than developing programs for existing hardware. After all, how many really new assembly instructions are there to keep up with?

But I'd like to point out an area where software development can become as tedious as hardware development: real-time-systems development. I'm speaking specifically of the case in which an idea for a new product based on real-time processing—an intelligent instrument, for example—has just been given the go-ahead for development. At this stage, the concerns of the hardware and the software designers are completely interwoven; they'll begin to diverge only later, after something resembling an initial prototype has been built. And there is never a guarantee that the hardware and software designers' respective concerns will not again converge tightly at some time prior to the shipping of production units.

True real-time computer programs are always synchronous—between any two task-terminal points, the program must tick off a constant number of clock cycles, regardless of the branching between the terminal points. Therefore, "cycle counting" is what the real-time programmer lives with from the beginning to the end of the project. Even slight improvements or changes in a real-time program can cause terrific problems in getting program branches to balance once again. The programmer may be forced to go to the hardware people and beg for more registers or hard-interrupt lines. I wonder how an AI program would perform if given the task of designing a true real-time system from scratch. Imagine the challenge of writing that AI program!

Berj N Ensanian
Associate Consultant
TATCO
Williamsport, PA

Make hardware and software designers a team

I suspect Jon Titus will get quite a bit of heat over the November 24 editorial (pg 51) on software designers having it easy. So what the heck, I'll start.

First of all, let's face the fact that it is becoming more and more difficult to design any electronic device without software knowledge. The "P" in "PLDs" stands for "programmable," and most designs are moving toward using these devices. The engineer must know how to program them. Most devices now use some sort of processor for all but the simplest tasks. The engineer must be able to do at least enough programming to test the device at the low level. And, in many cases, the designer follows through with actual application code, especially in embedded systems for control, communication, etc. It seems Brady Barnes must have followed this type of path when writing assembly code for his comm product.

But being able to code is only one aspect of the software life cycle, just as drawing a schematic is only one aspect of the hardware life cycle. There are parallels to the other observations Brady makes. It is true that op codes don't have lead times, but at least most people understand that a piece of hardware that is bought must be sent physically, and that takes time. They are often less likely to believe that software takes time. If a hardware designer says it takes six weeks to lay out a board and get film on it, everyone says "OK." If a software designer says it takes six weeks to design a module, nobody—probably not even the designer—knows whether this is true. As a result, software developers are often chastised for being behind schedule. Maybe we need to learn how to schedule better.

As for manufacturing influence, oh, that's nice. Someone decides that for some reason—cost reduction, board space, second sourcing, or whatever—something must change. So a device is changed, some switches are removed, and the next thing you know, the device doesn't work anymore. The new timer just doesn't program the way the old one did; some logic jumps into debug when switch 1 (now missing) is "On" (the state that's missing happens to give). No problem, they say. Just change the code. Works great, until somebody decides that the 80386 is really the way to go instead of the 68000, which the original prototype uses. And cost—Egad!—just the thought of having to add another 256k bytes of RAM because the code is too big is enough to send every coder back to square one with directions to clean it up and shrink it down. Reliability, testability, quality . . . forget it. *Shrink* it. Cost is paramount!

As for regulations, I wish there were a few more around. It really is very nice to be able to put a sticker on the box saying "FCC and UL approved." Nobody asks, nobody retests. They believe. I know of no place where you can get a sticker that says your code meets a standard. X.25 is X.25 is X.25, until you try to talk to a new system that sales just installed. And even if there *were* a big sticker on the

side saying "X.25 approved," if it doesn't work, the customer isn't happy, sales isn't happy, and you get to fix it—in the code, of course, because a hardware-specific change is too costly.

As for sales hype, well, I guess every industry is a little different. But a lot of shows are totally hardware oriented: how fast, how much memory, 32-bit technology, latest bus structure, newer peripherals, more storage, bits, bytes, and MIPS.

As for there being a battle between the two disciplines, maybe that's the start of the problem. If we could figure out how to approach a problem with team spirit aimed at solving the problem instead of building hardware and then writing software to work on it, we could improve relations between the two camps. And if hardware designers learned software life-cycle design, *not* how to code, then perhaps issues such as correctness, completeness, quality, and maintainability would become meaningful to them. That's not even a bad idea for software people who were trained as programmers.

No, design is not easy. There are many variables—space, performance, reliability. There are many complex decisions. There are schedule and cost pressures. In all disciplines. To produce quality products effectively requires effort, teamwork, and understanding of *all* the issues involved in every part of the team: electrical, electronic, mechanical, packaging, firmware, software, configuration control, quality assurance, manufacturing, test, certification, field support, publications, repair, shipping, management, marketing, and sales—from the products' inception until their obsolescence. Time spent on learning and understanding all these different viewpoints is time well spent. Ask Brady Barnes to write you again in 15 years. It will be interesting to see how he's done.

Phil Burtis
Director of Product Development
Contel Business Systems
Torrance, CA

Medium is the message

In recent years, I have noted an increase in the use of the word "media" as a singular in place of the proper singular term "medium." A glaring example of this error occurred in the October 27, 1988, issue of EDN, wherein an author wrote: "barium ferrite is now a thoroughly viable media" (pg 105).

Some may consider this to be a trivial point, but it bothers me to see the English language unneces-

CIRCLE NO 3

(and inconsistently) modified esult of authors' laziness. Let's et this word go the way of " and "datum."

Dzombak
rical Engineer
ametal Inc
gh, NC

Note: Oops! "Media" was in-used incorrectly, and our edi- should certainly have caught one before it went to press. We ly apologize.)

tum

able accompanying the article n-performance DSOs present with plenty of choices" (EDN, mber 22, 1988, pg 94) failed to that the Lecroy 9420 and 9450 both have glitch triggering. pologies for the oversight.

CMOS V_{OUT} DACs are available

It was puzzling to read in the letter from David E Johnson of Los Banos, CA, (Signals & Noise, EDN, October 27, 1988, pg 32) that manufacturers of D/A converters "have apparently not yet learned how to make CMOS voltage-output DACs."

Here are a few of the monolithic voltage-output CMOS DACs with onboard amplifiers that we at Analog Devices have been making during the past six years:

- The AD7226 quad, 8-bit V_{OUT} DAC (1983)
- The AD7224 8-bit, 1-LSB total-error overtemperature V_{OUT} DAC (1984)
- The AD7228 octuple voltage-output DAC (1987)
- The AD7245 12-bit, double-buffered CMOS DAC with output amp and voltage reference (1987)
- The AD7669 complete 8-bit I/O port with ADC and two V_{OUT} DACs (1988).

I don't know what David proposes as his "sermon for another time," but perhaps the time he had in mind was negative time (six years ago).

D H Sheingold
Analog Devices
Norwood, MA

YOUR TURN

EDN's Signals and Noise column provides a forum for readers to express their opinions on issues raised in the magazine's articles or on any topic that affects the engineering industry. Send your letters to the Signals and Noise Editor, 275 Washington St, Newton, MA 02158. We welcome all comments, pro or con. All letters must be signed, but we will withhold your name upon request. We reserve the right to edit letters for space and clarity.

MAXIM DESIGN NEWS

Analog Design Insights from Maxim Integrated Products April '89

New Small DACs Offer Serial/Parallel Operation

Recent advances in the design of digital-to-analog converters (DACs) make it likely that today's newer devices can enhance the performance of your next design. Many of these converters offer *smaller size, higher functional integration, and more versatile digital interfaces.* The key to selecting the right DAC for your application is developing an understanding of how these newer products compare to their predecessors and how they meet the changing needs of system designs.

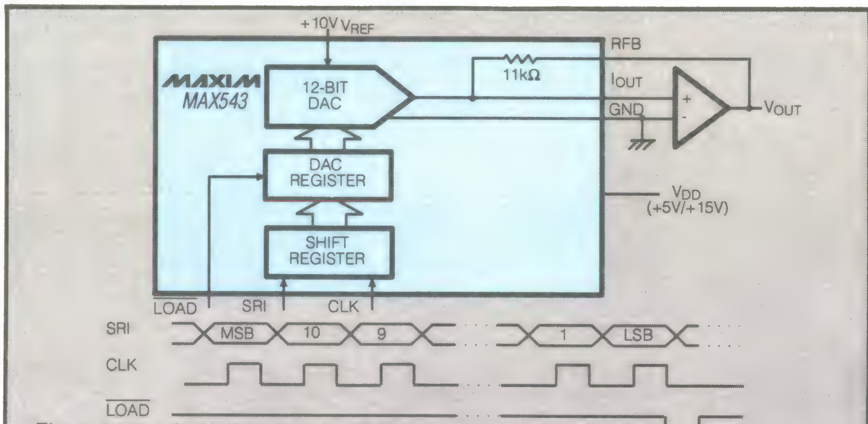


Fig. 1. 3-Wire Serial Interface 12-Bit DAC

Serial I/O Advantages

The increasing popularity of serial interfacing is directly proportional to the growing number of processors with serial ports. The serial interface reduces the noise problems experienced when parallel input DACs are used with a µP bus. The digital transitions from the bus couple to the DAC's output through the DAC package (pin-to-pin capacitances), unless the bus is kept inactive while the DAC is being used. Alternatives call for the use of a dedicated I/O bus, or isolating the DAC from the bus with external buffer registers -- both, costly solutions. Serial interface is also preferred for voltage isolation or ground-loop elimination since the two- or three-wire serial interface lines can be opto- or transformer-isolated at a lower cost than a parallel interface. For instance, *two new serial input digital-to-analog converters from Maxim - the quad 8-bit MAX500 and the 12-bit MAX543 - help reduce system size and cost by reducing the footprint area and the number of signal traces on a circuit board.*

12-Bits in 8-Pin Mini-DIP

The serial input MAX543 is a CMOS 12-bit, current output, multiplying DAC that comes in an 8-pin DIP package (Figure 1). Its serial interface uses three signal lines: SRI (serial input), CLK (clock), and LOAD (load). Rising edges of CLK shift the data at SRI into a shift register inside the MAX543. The LOAD signal transfers this data in the shift register into the DAC. The LOAD signal prohibits the DAC output from changing during the time SRI is shifted into the MAX543, and allows for the simultaneous updating of all DACs in a multi-DAC system.

In a typical voltage output application, the MAX543 requires a voltage reference and an output amplifier. These two components can be selected to fit specific requirements, making the MAX543 a versatile DAC. Since the MAX543 is specified with both +5V and +15V supplies, it can be used in digital systems with +5V logic supply, or when low noise performance is important, it can be used with an analog +15V supply.

2-Wire Serial Quad DAC

The new MAX500 also works with a 2-wire or 3-wire serial interface (Figure 2). It packs four voltage output DACs with buffer amplifiers in a 16-pin DIP or SO package. In the 3-wire mode, the MAX500 uses SDA (serial data), SCL (serial clock), and LOAD signals to shift 10-bits (8-bits data, 2-bits address) into a shift register in the MAX500. LOAD signal transfers the data from the shift register into a separate register for the addressed DAC. A master LDAC (load DAC) signal updates all four DACs in the MAX500 simultaneously. An SRO (serial output) pin allows for cascading of the SDA pin to the SRO. This enables a µP to shift data to multiple DACs in a system using a single data line.

The two-wire mode uses a start condition to shift data into the MAX500, and a stop condition to update the DACs from the shift register (Figure 3, pg. 2).

8 DACs in One Package

Multiple voltage output DACs such as the MAX500 or Maxim's AD7228 are particularly useful in correcting gain and offset errors in systems, replacing problem ridden trim-pots. *The AD7228 packs eight 8-bit DACs and their output buffers into a 24-pin package and maintains 8-bit accuracy over the full operating temperature range without external components or trimming.* Each of the eight DACs within the AD7228 contains an individual latch that accepts and holds data written by the system µP, similar to an address in system memory. Data is transferred into these latches through a common 8-bit input port with TTL and +5V-CMOS compatible digital inputs. Like the MAX500, the output of each DAC within the AD7228 provides up to +10V into a 2kΩ and 100 pF load with a settling time of 5 µs. An optional -5V supply can be used to improve the output current sink capability.

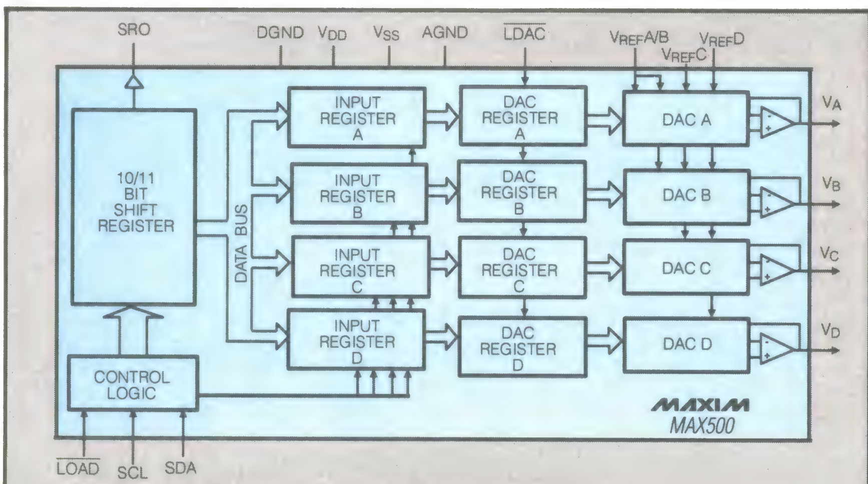


Fig. 2. 2- or 3-Wire Serial Input Quad 8-Bit DAC

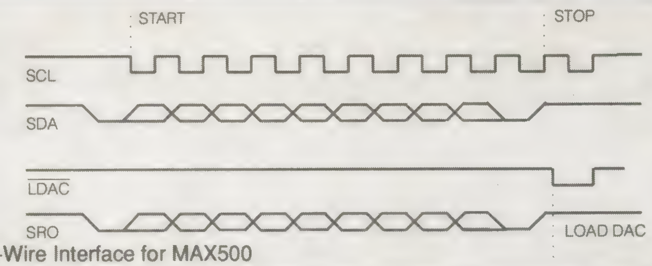


Fig. 3. 2-Wire Interface for MAX500

DACs for Single Supply Applications

Although current output DACs like the MAX543 are best suited for use in multiplying applications such as audio attenuators, programmable gain amplifiers, and function generators, they can also be used in the "voltage mode" (Figure 4). This mode is useful when either single supply operation is required or the output voltage needs to be the same polarity as the reference. Also, the voltage settling time in this mode is relatively fast since the DAC output capacitance is very small. Those applications that allow a high output impedance DAC can use this mode without a buffer amplifier. Maxim's AD7548, used in this example, interfaces to 8-bit μPs conveniently. It supports right/left justified, MS-byte/LS-byte data inputs, zero- and full-scale override functions that make offset and gain adjustments easy. *Maxim's AD7548 works with +5V, +12V, or +15V supplies, and maintains TTL and +5V CMOS compatibility with any of these supply voltages.*

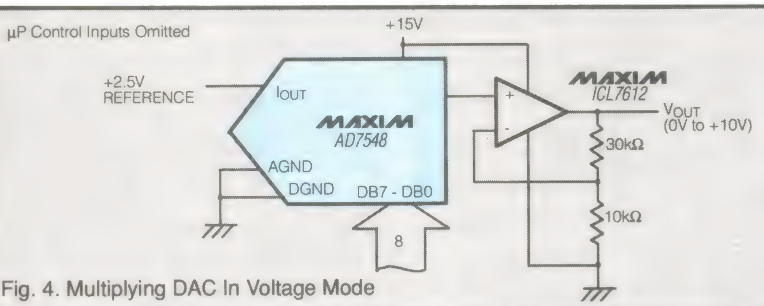


Fig. 4. Multiplying DAC In Voltage Mode

DAC SELECTION GUIDE

Part Number	Resolution (BITS)	Settling Time (μS)	Number Of DACs Per Pkg.	Output Type	Interface Type	Supply Voltage (V)
AD7523	8	0.15	1	I	LOGIC	+15
AD7524	8	0.25	1	I	8-bit μP	+5 or +15
MAX7624	**8**	**0.25**	**1**	**I**	**8-bit μP**	**+12 to +15**
AD7528	8	0.18	2	I	8-bit μP	+5 or +15
AD7628	8	0.35	2	I	8-bit μP	+12 to +15
AD7224	8	5.0	1	V	8-bit μP	+12 to +15
AD7225	8	4.0	4	V	8-bit μP	+12 to +15
AD7226	8	4.0	4	V	8-bit μP	+12 to +15
AD7228	8	5.0	8	V	8-bit μP	+5 or +15
MAX500	**8**	**5.0**	**4**	**V**	**SERIAL**	**+12 to +15**
AD7520	10	(0.5)	1	I	LOGIC	+15
AD7530	10	(0.5)	1	I	LOGIC	+15
AD7533	10	0.6	1	I	LOGIC	+15
AD565A	12	0.25	1	I	LOGIC	+15
AD566A	12	0.35	1	I	LOGIC	-15
AD7521	12	0.5	1	I	LOGIC	+15
AD7531	12	0.5	1	I	LOGIC	+15
AD7541	12	1.0	1	I	LOGIC	+15
AD7541A	12	1.0	1	I	LOGIC	+15
AD7542	12	2.0	1	I	4-bit μP	+5
AD7543	12	2.0	1	I	SERIAL	+5
AD7545	12	2.0	1	I	12-bit μP	+5, +15
AD7545A	12	1.0	1	I	12-bit μP	+5, +15
AD7548	12	1.0	1	I	8-bit μP	+5 or +15
MAX543	**12**	**1.0**	**1**	**I**	**SERIAL**	**+5 or +15**
MAX7645	**12**	**1**	**1**	**I**	**12-bit μP**	**+15**
AD7534	14	1.5	1	I	8-bit μP	+12 to +15
AD7535	14	1.5	1	I	8/14-bit μP	+12 to +15
AD7536	14	1.5	1	I	8/14-bit μP	+12 to +15

Improved Accuracy Over Temperature

Maxim's AD7534, AD7535, and AD7536 offer 14-bit resolution and an accuracy of ±600μV when used with a +10V reference. Their monolithic CMOS construction, laser trimmed thin-film resistors, and temperature compensated design results in very low tempcos — less than 1ppm/°C for INL and DNL and 0.5 ppm/°C for gain, making applications over wide temperature ranges feasible. Output leakage current of CMOS current-output DACs usually increases significantly at high temperatures. These new DACs are an exception since they can be used at +125°C with less than 20nA of output leakage. Maxim's AD7536 is optimized to work with bipolar outputs and contains all the necessary resistors on-chip for four-quadrant operation requiring only two external op-amps and a reference voltage. *Maxim's AD7534/5/6 can be conveniently used to upgrade older 12-bit designs, or to improve the performance of those applications that need to work over a wide temperature range.*

Perhaps the most important criterion in selecting DACs should be the quality and the reliability of the devices. Maxim pays special attention to quality by designing *all digital inputs to typically withstand over 5000V of electrostatic discharge (ESD) and 50 mA of electrical over-stress (EOS). Also, all products in DIPs are 100% burned-in,* thus eliminating infant mortality failures and uncovering other potential reliability problems before devices are sold.

★ FREE ★ Data Sheets:

(CIRCLE 10)	MAX500
(CIRCLE 11)	MAX543
(CIRCLE 12)	AD7228
(CIRCLE 13)	AD7548
(CIRCLE 14)	AD7534/5/6

References:

(CIRCLE 15)	Maxim's Analog Devices Cross Reference Guide
(CIRCLE 16)	1988/89 Analog Applications Handbook

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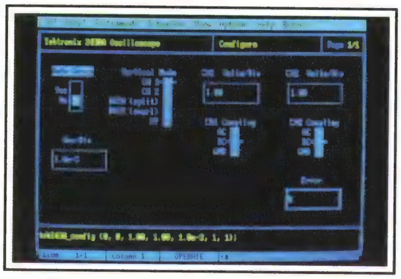
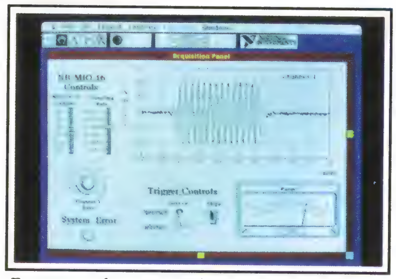


Intuitive character-based function panels that automatically generate source code.



Front panel user interface with virtual instrument block diagram programming.

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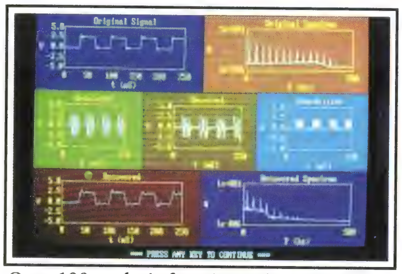
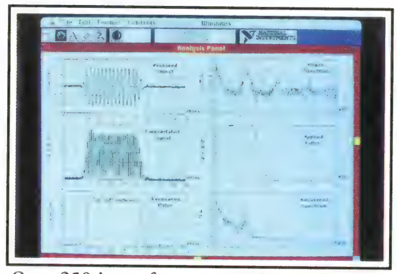


Over 100 analysis functions plus all the built-in functions of your language.



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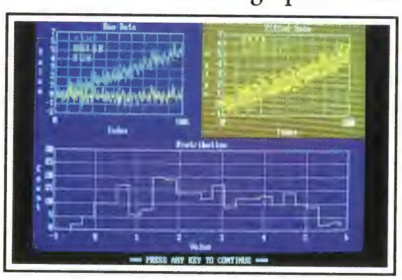

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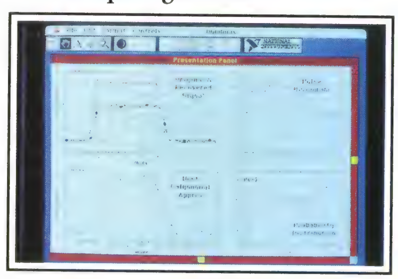

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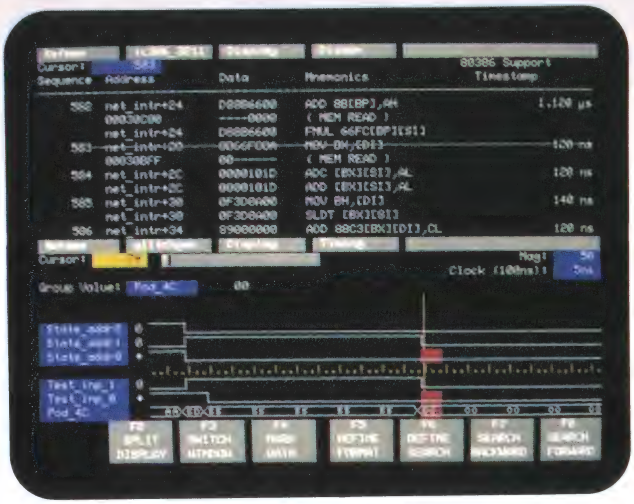

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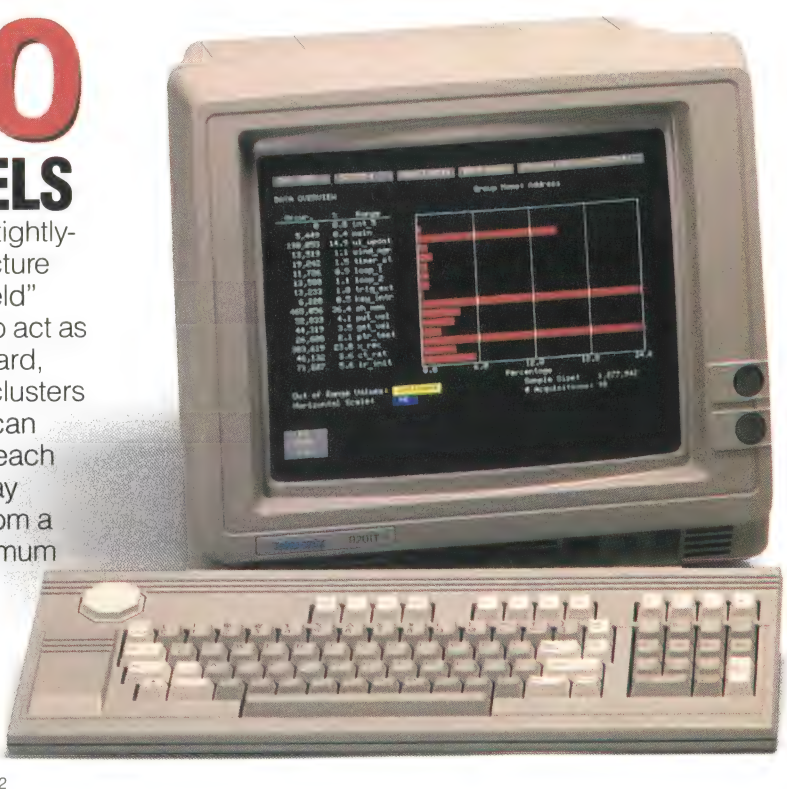
540 CHANNELS

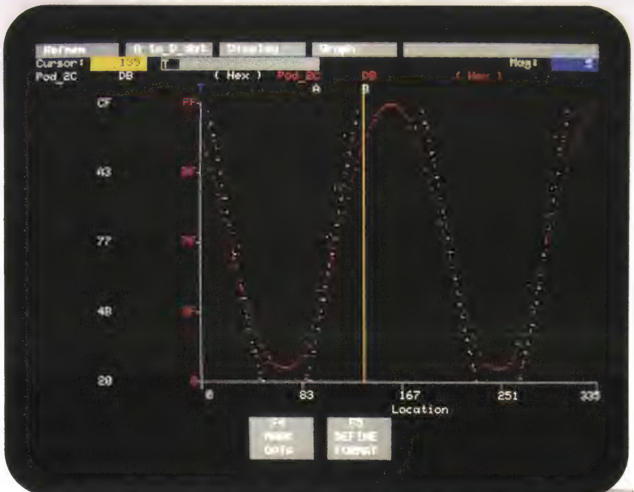
The DAS 9200's tightly-coupled architecture allows you to "weld" cards together to act as a single, wider card, or as individual clusters of modules that can trigger and arm each other, then display information as from a single unit. Maximum configuration: 540 acquisition channels or 1008 stimulus channels.



Version 2

once, with true time-correlation of all data.

Monitor the integration of dedicated I/O processors relative to the Main CPU. Test communications links between processors. Display disassembly activity together with high-resolution timing information to relate logic problems relative to specific events.



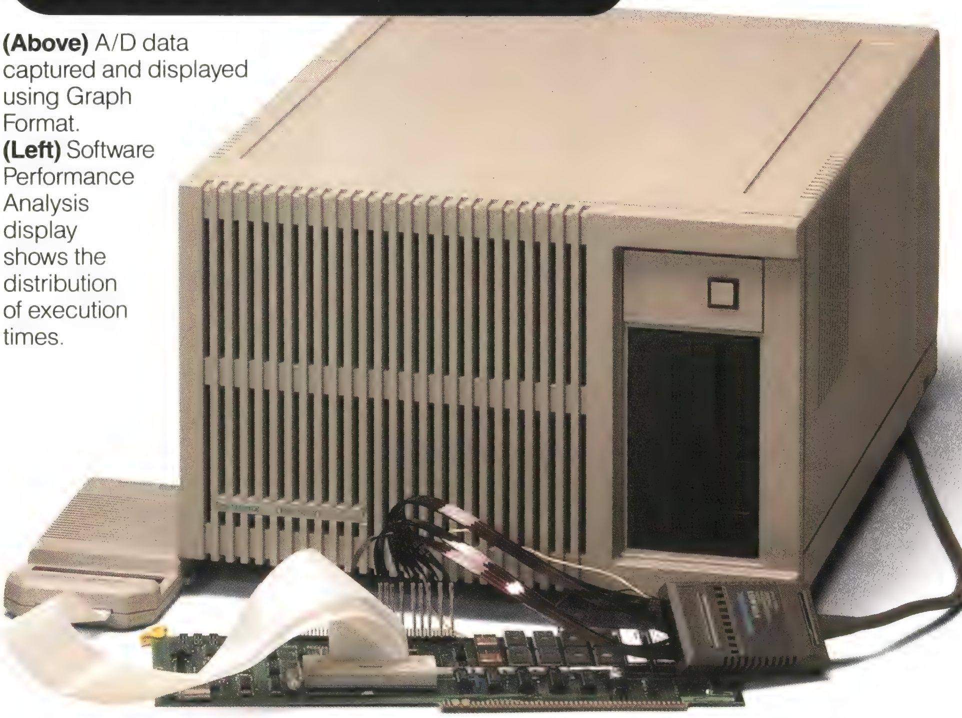
2 GHz

For applications requiring nanosecond edge resolution, the 92HS8 High-Speed Timing Module gives you 2 GHz bandwidth and a 500 ps sample interval, supported by a <1 pf input capacitance probe that eliminates common-mode noise and circuit loading. The 92HS8 also welds together to serve wide, parallel applications with no width/speed tradeoffs.

One new asked-for option is the 92LAN card, allowing the DAS to act a network node for efficient file transfer.

Add in its new 8 MB memory for fast response, new 40 MB hard disk, standard, and an assortment of software enhancements, and you see that the DAS not only started in a league by itself. It's staying there.

To find out more about the DAS 9200, contact your Tek representative, or call 1-800-245-2036. In Oregon, 231-1220.



(Above) A/D data captured and displayed using Graph Format.
(Left) Software Performance Analysis display shows the distribution of execution times.

MORE TO COME

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Powerful DSP Support Tools from Oki

Oki helps you achieve faster, easier DSP application development with a complete portfolio of support tools.

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A full set of powerful DSP support tools

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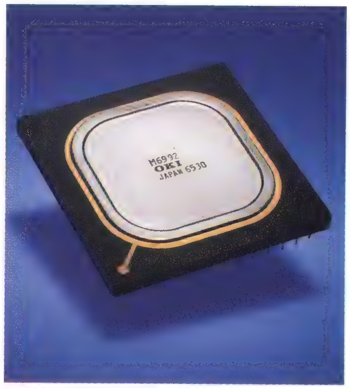
▶ *Emulators*—Oki offers a choice of stand-alone in-circuit emulators for real-time emulation, with the EMU92 and EMU92L.

▶ *Software Libraries of User Routines*—these libraries contain many of the most commonly used routines in DSP programming.

▶ *Development System*—the PSP92 permits real-time processing of analog signals through separate "digital" and "analog" PC-AT cards. It also allows for sophisticated 16-color EGA-compatible graphics.



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EDN051189

Streamline DSP with Oki

☐ Please send me your new brochure *Keys to faster, easier DSP application development* containing detailed technical data/specs on Oki's MSM6992/10 DSP devices and complete portfolio of DSP support tools.

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CIRCLE NO 69

CALENDAR

User Symposium/89, Austin, TX. Janet Hill, National Instruments Corp, 12109 Technology Blvd, Austin, TX 78727. (800) 433-3488. FAX 512-250-9319. May 14 to 16.

International Symposium on Measurement Technology and Intelligent Instruments, Wuhan, Hubei Province, People's Republic of China. Dr. Shawn Buckley, Cochlea Corp, 985 Timothy Dr, San Jose, CA 95133. (408) 920-2650. May 15 to 17.

Custom Integrated Circuits Conference, San Diego, CA. Marc Hartranft, Cypress Semiconductor, 3901 N First St, San Jose, CA 95134. (408) 943-2681. May 15 to 18.

Tape Automated Bonding (TAB) Workshop, Sunnyvale, CA. Dr Subash Khadpe, Semiconductor Technology Center, Box 38, Neffs, PA 18065. (215) 799-0919. May 25 to 26.

43rd Annual Frequency Control Symposium, Denver, CO. Dr R L Filler, US Army Electronics Technology and Devices Laboratory, Attn: SLCET-EQ, Fort Monmouth, NJ 07703. (201) 544-2467. May 31 to June 2.

CASE Benchmarks: A Seminar Comparing Leading CASE Tools, Toronto, Ontario, Canada. Digital Consulting Inc, 6 Windsor St, Andover, MA 01810. (508) 470-3880. June 5 to 7.

Design to Test (seminar), Minnetonka, MN. Logical Solutions Technology Inc, 310 W Hamilton Ave, Suite 101, Campbell, CA 95008. (408) 374-3650. June 6 to 7.

Troubleshooting Microprocessor-Based Equipment and Digital Devices (seminar), Portland, OR. Micro Systems Institute, 73 Institute Rd, Garnett, KS 66032. (913) 898-4695. June 13 to 16.

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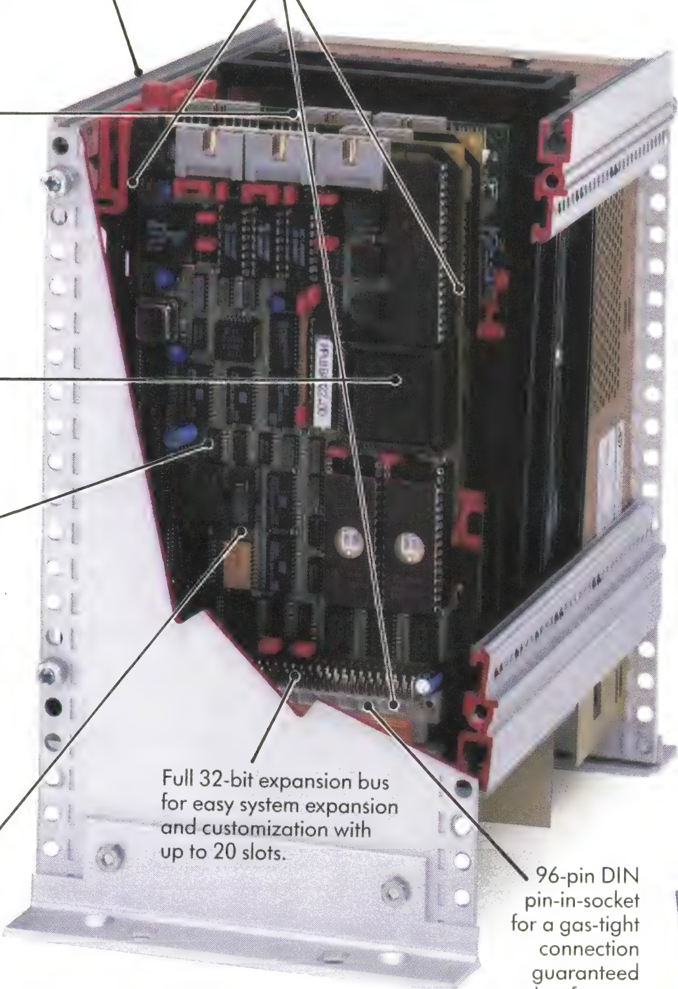
Compact single height Eurocard board format (100 x 160 mm) that doesn't flex or bend and withstands the toughest shock and vibrations.



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CIRCLE NO 167

CALENDAR

ATE & Instrumentation Conference East, Boston, MA. MG Expositions Group, 1050 Commonwealth Ave, Boston, MA 02215. (800) 223-7126; in MA, (617) 232-3976. June 19 to 22.

COMPASS '89 Conference, Gaithersburg, MD. Nettie Quartana, 2100 Washington Blvd, Arlington, VA 22204. (703) 486-3500. June 20 to 22.

Introduction to X.25 (short course), College Park, MD. University of Maryland University College Center for Professional Development, University Blvd at Adelphi Rd, College Park, MD 20742. (301) 985-7122. June 20 to 22.

VHDL and Modeling in the DoD Procurement Process (seminar), Washington, DC. Paul Hunter, Program Chair, NRL, Code 5305, Washington, DC 20375. (202) 767-3264. June 21 to 23.

Fiber Optics in Local Communications (seminar), New York, NY. Raycom Systems Inc, 6395 Gunpark Dr, Boulder, CO 80301. (800) 288-1620. June 22.

Knowledge Engineering Today's Marketplace, The Annual Conference of the International Association of Knowledge Engineers, College Park, MD. Fred Whiting, IAKE Conference, Georgetown Box 25461, Washington, DC 20007. (301) 231-7826. June 26 to 28.

OS/2: A Comprehensive Hands-On Introduction (short course), Ottawa, Canada. John Valenti, Integrated Computer Systems, 5800 Hannum Ave, Culver City, CA 90231. (800) 421-8166; in Canada, (800) 267-7014. June 27 to 30.

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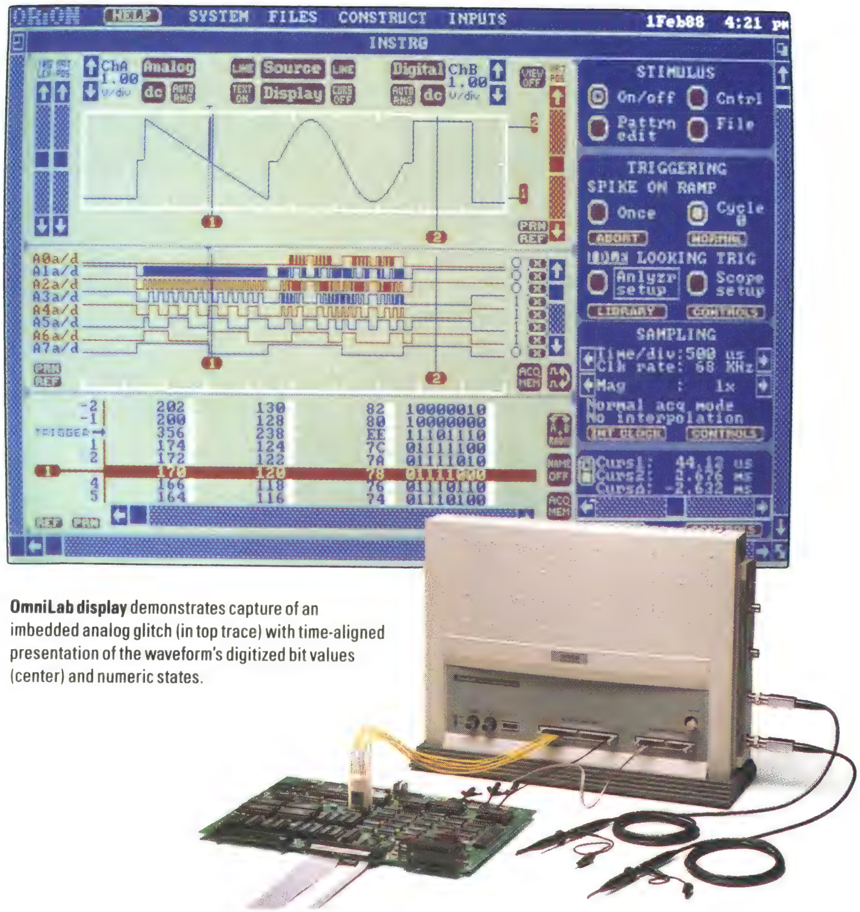

OmniLab display demonstrates capture of an imbedded analog glitch (in top trace) with time-aligned presentation of the waveform's digitized bit values (center) and numeric states.

■ Only ORION delivers next-generation high performance integrated digital scope-logic analyzer with . . .

■ Precisely time-aligned analog and digital traces.

Our 9240 is a whole new class of instrument that vastly simplifies development. It lets you watch time-correlated digital and analog signals from the same circuit—on the same screen at the same time. And with nano-second correlation.

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NO-COMPROMISE 9240 SPECIFICATIONS

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Digitizers:	Two, 8 bit
Bandwidth:	100 MHz
Single-Shot Digitizing:	34 S/s to 204 MS/s
Repetitive Sampling:	680 MS/s
Scale Factor:	10 mV/div to 10V/div in 1-2-5 sequence
Record Length:	4K (16K optional)

LOGIC ANALYZER

Inputs:	48, timing and state
Asynchronous Clocking:	34 MS/s on 48 inputs; 204 MS/s on 8 inputs
Repetitive Sampling:	680 MS/s on 48 inputs
Synchronous Clocking:	0 to 34 MS/s
Acquisition Memory:	4K samples (16K optional)
Disassembly Options:	Over 33 microprocessors

ANALOG STIMULUS

Output:	8mV to 8 V peak-to-peak, 8 bit
Cycle Length:	4 to 4K samples (16K optional)
Clocking:	34 S/s to 34 MS/s
Functions:	Record, edit and playback

DIGITAL STIMULUS

Outputs:	24, 74F tri-state drivers
Cycle Length:	4 to 4K samples (16K optional)
Timing:	34S/s to 34MS/s
Functions:	Record, edit and playback

ORION INSTRUMENTS

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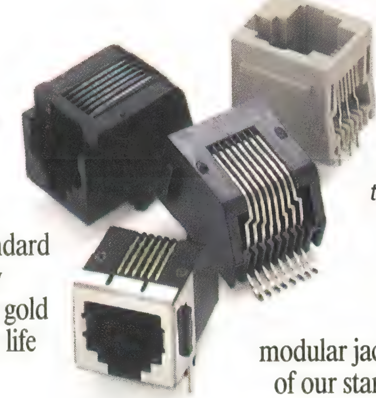
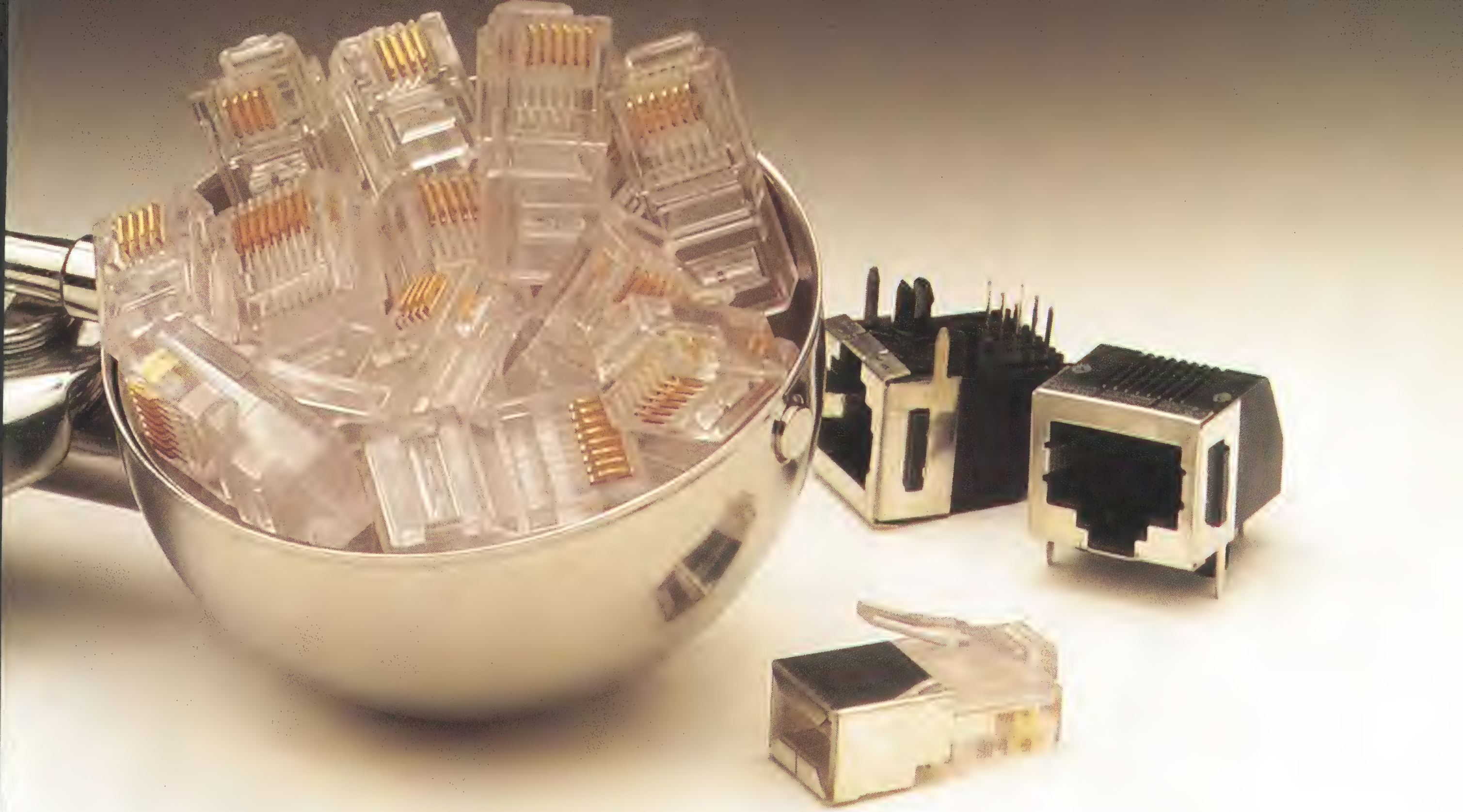
We offer you the standards. Preloaded plugs that mass terminate round or flat-oval wire. And our standard top- and side-entry jacks with selective gold contacts for longer life at lower cost.



Shielded mod plugs in fully-loaded 6- and 8-position versions have insulation-piercing terminals. Shielded jacks in board-ground or panel-ground designs.

Or the surface-mount modular jacks. With all the features of our standard line in low-profile, vapor-phase-compatible modules that integrate easily with accepted processing, even robotic insertion.



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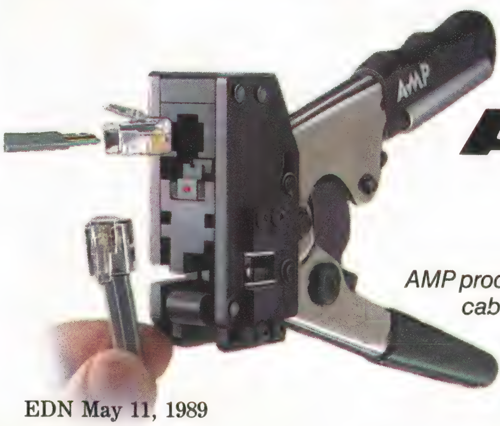

AMP **Interconnecting ideas**

AMP production hand tool cuts cable, strips cable jacket, and mass terminates loose-piece plugs.

CIRCLE NO 95

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Waste not, want not

Jon Titus

Dave Wilson

Steve Weitzner

Over the years, many communities have sought to attract light industries. Typically, the ideal industries are those that put a lot of value in small packages and that produce few if any waste products that might foul the environment. Up until a few years ago, there appeared to be many such "clean" businesses in the electronics industry. However, today we realize that our own industry has its share of environmental problems—many of the solvents and chemicals we use, and the by-products and wastes we produce, harm our environment.

To many people it seems that worries about the environment surfaced in the 60s, when many concerned citizens petitioned government bodies and industrial groups to cut down on smog and automobile emissions. Similarly, there were groups that sought to protect natural resources, such as open grassland, redwood forests, or waterfront property. Actually, concerns about the environment go back many, many years and you'll find one thought-provoking message from the 1800s on pg 51.

The person who wrote what you're about to read was an American Indian, Chief Seattle, who wrote to President Franklin Pierce in 1854. Pierce wanted the US to buy a large portion of Indian land and he promised the Indians a large reservation in return. Read Chief Seattle's words carefully; they still ring true over 100 years later. We hope you'll keep the chief's words in mind as you go about your engineering work. Each of us can do a better job guarding and restoring our environment.

The letter from Chief Seattle is being printed in three publications that serve electronics professionals: *ESD*, *Electronic Engineering Times*, and *EDN*. This type of coordinated publishing effort is unusual, but the editors of each publication think that the environment is a serious issue—one we need to discuss and act upon quickly. None of us wants to pass on a dirty and polluted planet to our offspring, yet that's exactly what will happen if we continue business as usual. Solvents escape into the upper atmosphere and destroy our ozone layer, solid waste leaches into the groundwater, and toxic and carcinogenic materials pass into our food chain.

Obviously, not all of these polluting chemicals arise from the electronics industry, but some do. It's our industry, so it's up to us to propose changes and remedies. If we leave the pollution problems for much longer, cleanup costs will skyrocket and the government will intervene to force expensive and bureaucratic solutions upon us. We have only a very short time in which we can decide whether or not to hold ourselves responsible for the environment. Chief Seattle said that we *are* responsible for our own environmental actions and that we have a duty to preserve the continuing good health of the Earth. We agree.

Jon Titus

Jon Titus
Editor/Editorial Director, *EDN*

Steve Weitzner
Editor, *Electronic Engineering Times*

Chief Seattle Speaks

How can you buy or sell the sky, the warmth of the land? The idea is strange to us. If we do not own the freshness of the air and the sparkle of the water, how can you buy them?

Every part of this earth is sacred to my people. Every shining pine needle, every sandy shore, every mist in the dark woods, every clearing, and humming insect is holy in the memory and experience of my people. The sap which courses through the trees carries the memories of the red man.

The white man's dead forget the country of their birth when they go to walk among the stars. Our dead never forget this beautiful earth, for it is the mother of the red man. We are part of the earth and it is a part of us. The perfumed flowers are our sisters; the deer, the horse, the great eagle, these are our brothers. The rocky crests, the juices in the meadows, the body heat of the pony, and man—all belong to the same family.

So, when the Great Chief in Washington sends word that he wishes to buy our land, he asks much of us. The Great Chief sends word he will reserve us a place so that we can live comfortably to ourselves. He will be our father and we will be his children. So we will consider your offer to buy our land. But it will not be easy. For this land is sacred to us.

This shining water that moves in the streams and rivers is not just water but the blood of our ancestors. If we sell you land, you must remember that it is sacred, and you must teach your children that it is sacred and that each ghastly reflection in the clear water of the lake tells of events and memories in the life of my people. The water's murmur is the voice of my father's father.

The rivers are our brothers, they quench our thirst. The rivers carry our canoes, and feed our children. If we sell you our land, you must remember, and teach your children that the rivers are our brothers, and yours, and you must henceforth give the rivers the kindness you would give any brother.

We know that the white man does not understand our ways. One portion of land is the same to him as the next, for he is a stranger who comes in the night and takes from the land whatever he needs. The earth is not his brother but his enemy, and when he has conquered it, he moves on. He leaves his fathers' graves and his children's birthright is forgotten. He treats his mother, the earth, and his brother, the sky, as things to be bought, plundered, sold like sheep or bright beads. His appetite will devour the earth and leave behind only a desert.

I do not know. Our ways are different from your ways. The sight of your cities pains the eyes of the red man. But perhaps it is because the red man is a savage and does not understand.

There is no quiet place in the white man's cities. No place to hear the unfurling of leaves in spring, or the rustle of an insect's wings. But perhaps it is because I am a savage and do not understand. The clatter only seems to insult the ears. And what is there to life if a man cannot hear the lonely cry of the whippoorwill or the arguments of the frogs around a pond at night? I am a red man and do not understand. The Indian prefers the soft sound of the wind darting over the face of a pond, and the smell of the wind itself, cleansed by rain or scented with the pine cone.

The air is precious to the red man, for all things share the same breath: the beast, the tree, the man, they all share the same breath. The white men, they all share the same breath. The white man does not seem to notice the air he breathes. Like a man dying for many days, he is numb to the stench. But if we sell you our land, you must remember that the air is precious to us, that the air shares its spirit with all life it supports. The wind that gave our grandfather his first breath also received his last sigh. And if we sell you our land, you must keep it apart and sacred, as a place where even the white man can go to taste the wind that is sweetened by the meadow's flowers.

So we will consider your offer to buy our land. If we decide to accept I will make one condition. The white man must treat the beasts of this land as his brothers.

I am savage and I do not understand any other way. I have seen a thousand rotting buffalos on the prairie, left by the white man who shot them from a passing train. I am a savage and I do not understand how the smoking iron horse can be more important than the buffalo that we kill only to stay alive.

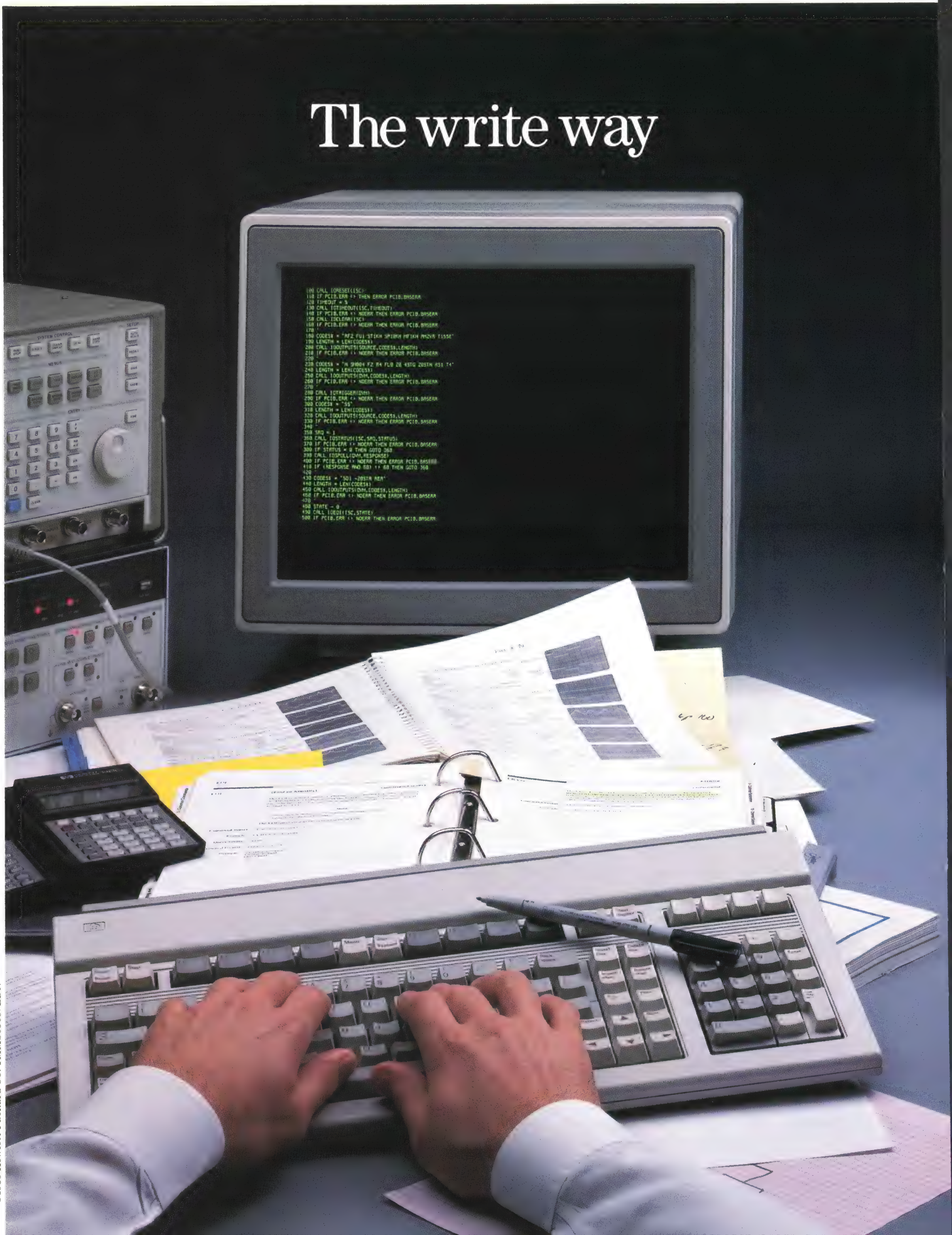
What is man without the beasts? If all the beasts were gone, man would die from a great loneliness of spirit. For whatever happens to the beasts, soon happens to man. All things are connected.

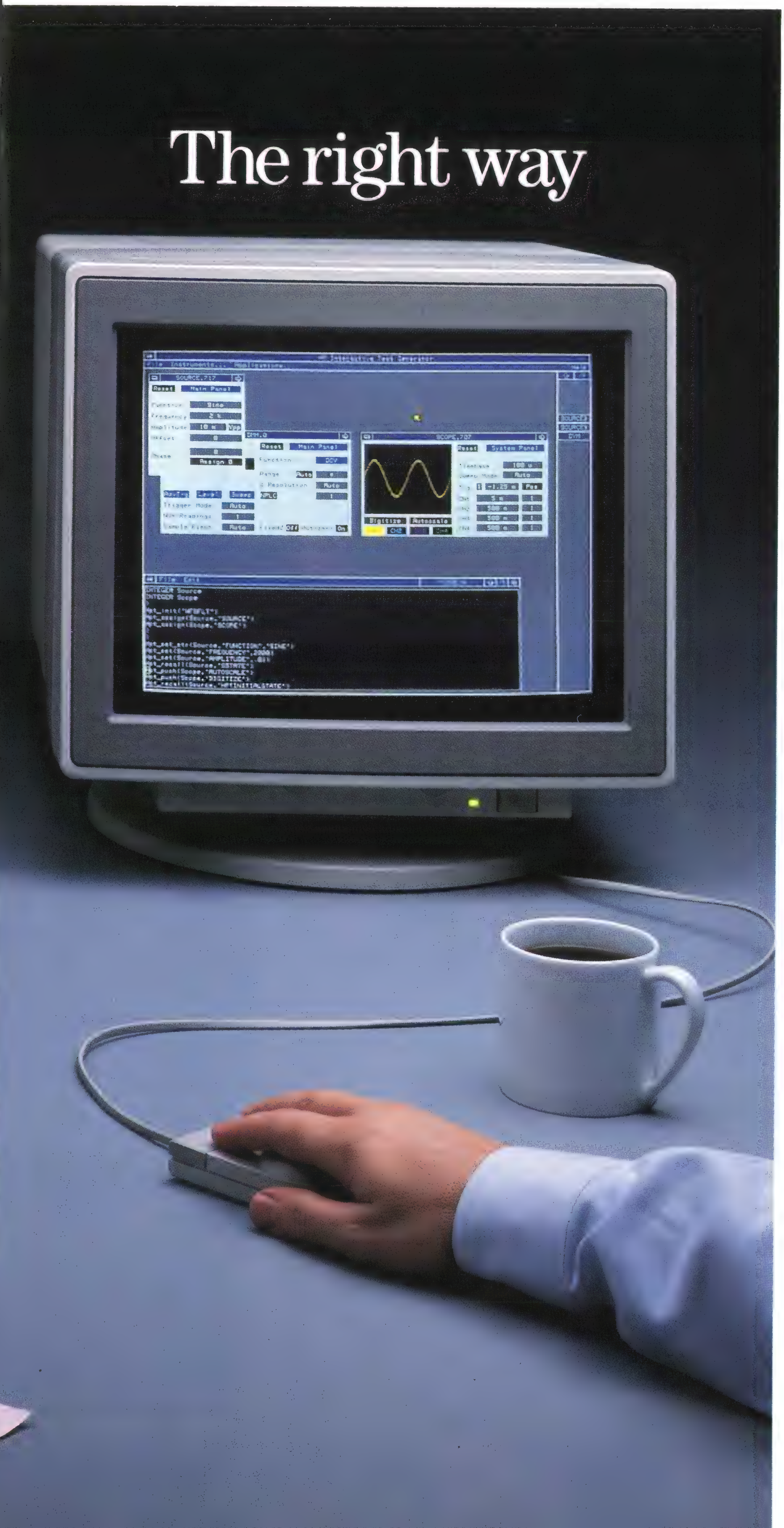
You must teach your children that the ground beneath their feet is the ashes of our grandfathers. So that they will respect the land, tell your children that the earth is rich with the lives of our kin. Teach your children what we have taught our children, that the earth is our mother. Whatever befalls the earth befalls the sons of the earth. Man did not weave the web of life, he is merely a strand in it. Whatever he does to the web, he does to himself.

Even the white man, whose God walks and talks with him as friend to friend, cannot be exempt from the common destiny. We may be brothers after all. We shall see. One thing we know, which the white man may one day discover—our God is the same God. You may think now that you own Him as you wish to own our land; but you cannot. He is the God of man and his compassion is equal for the red man and the white. The earth is precious to him, and to harm the earth is to heap contempt upon its Creator. The Whites, too, shall pass; perhaps sooner than all other tribes. Contaminate your bed and you will one night suffocate in your own waste.

But in your perishing, you will shine brightly, fired by the strength of the God who brought you to this land and for some special purpose gave you dominion over this land and over the red man. That destiny is a mystery to us, for we do not understand when the buffalo are all slaughtered, the wild horses are tamed, the secret corners of the forest heavy with the scent of many men, and the view of the ripe hills blotted out by talking wires. Where is the thicket? Gone. Where is the eagle? Gone.

Test development today:





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See for yourself how HP ITG works. Call your local HP sales office today. We'll send you a FREE demo disk with all the details. Right away.

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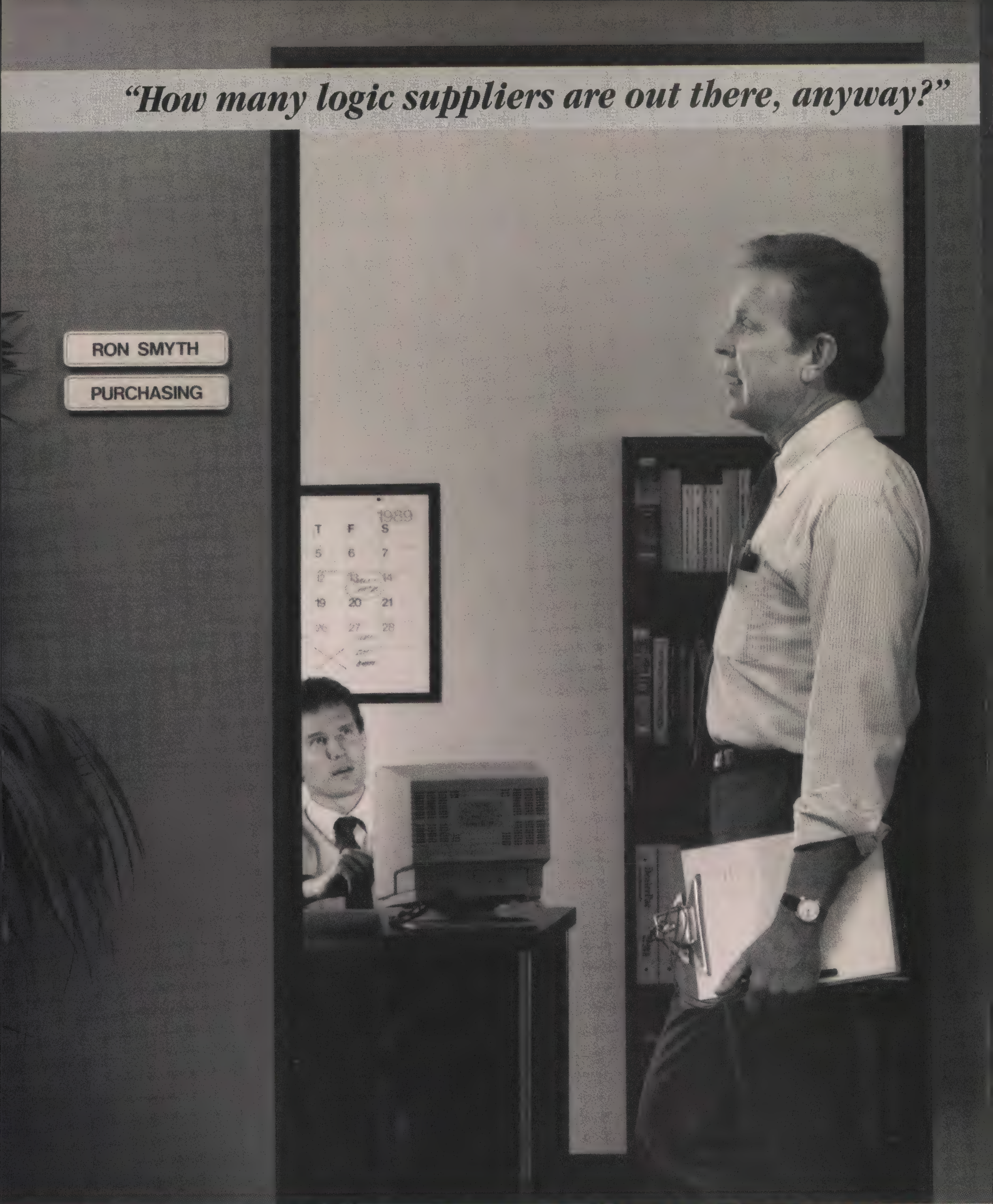
CIRCLE NO 55

"How many logic suppliers are out there, anyway?"



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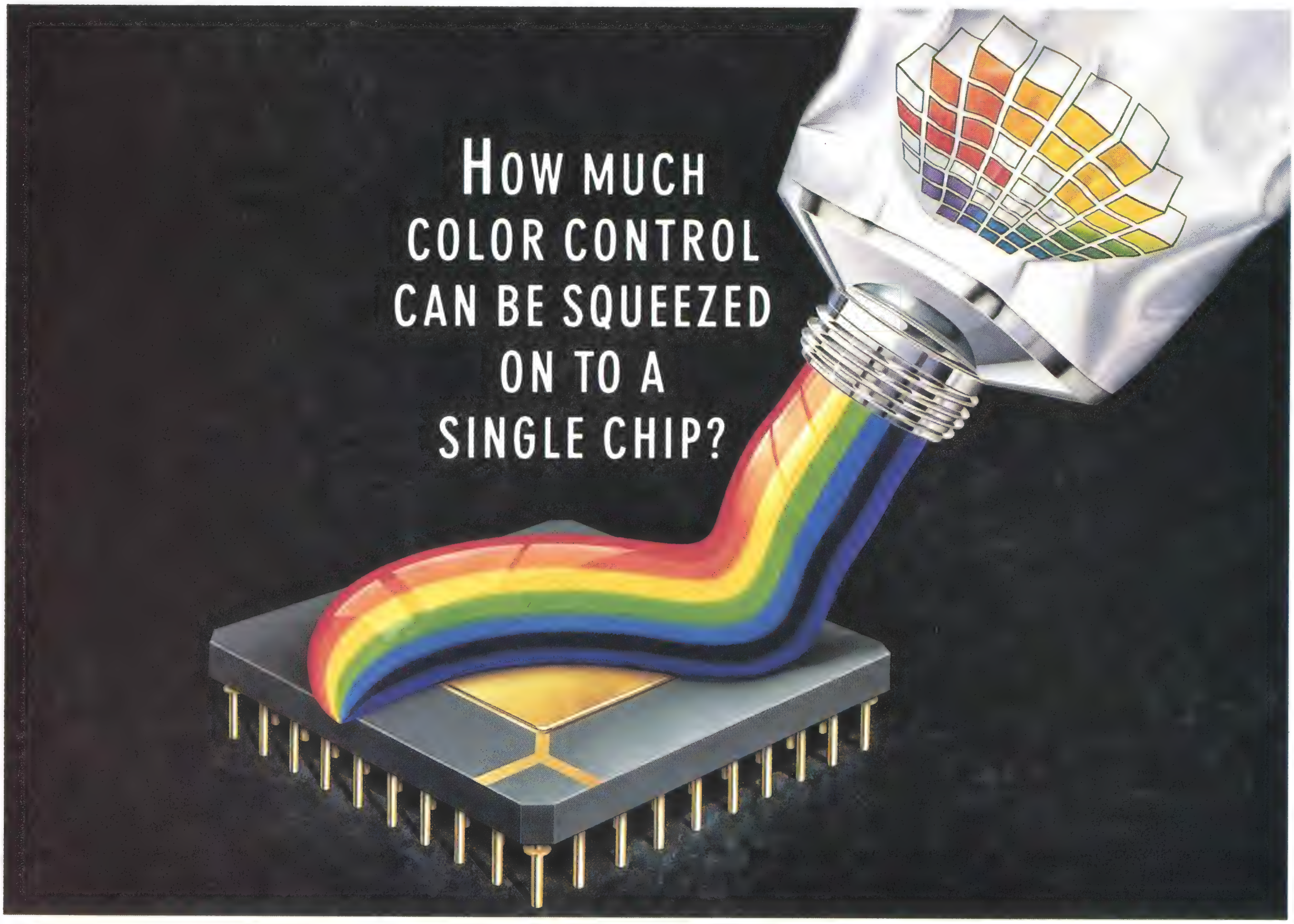

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REWRITABLE OPTICAL-DISK DRIVES

Optical units provide mass storage

Rewritable optical-disk drives may not match the speed of hard-disk drives, but their high density, transportability, and data-security capabilities exceed other mass-storage media.

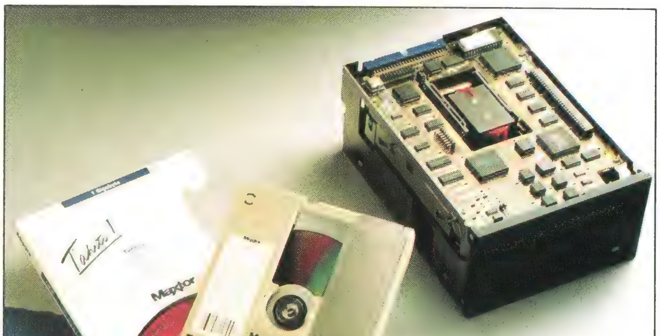
Chris Terry,
Associate Editor

Although read-only and WORM (write once, read mostly) optical-storage units have been available for several years, rewritable (erasable) optical storage is only now becoming available. When you're evaluating these optical-disk drives and other mass-storage units, you must consider not only the obvious factors of storage capacity, access time, and interfacing requirements, but also less obvious requirements that may be implicit in your application. Among these factors are reliability, security, ease and speed of backup, transportability of data, interchangeability of removable media, and cost.

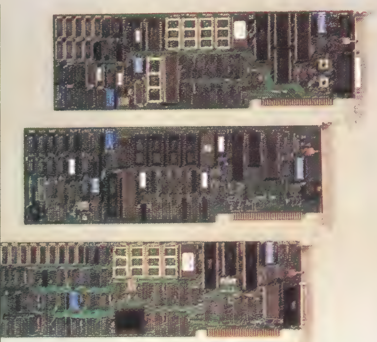
Rewritable optical units satisfy many of these criteria for selecting a reliable mass-storage medium. One drawback, however, is that their data-access times are relatively slow compared to those of Winchester drives. Nevertheless, as long as speed isn't your primary concern, rewritable optical units are ideal for many applications, such as the storage of archival information. However, don't expect to see these units completely replace disk and tape storage media in the foreseeable future. Instead, you'll probably find new systems that incorporate both magnetic and optical storage units and emphasize the best characteristics of each medium.

One of the main advantages of optical storage, whether it's CD-ROM, WORM, or rewritable, is its high storage capacity. A single 5¼-in. rewritable cartridge can accommodate either 500M bytes (single-sided) or 1G byte (double-sided) of unformatted storage—approximately 66.6M bytes per cubic inch. Considering the off-line storage volume required for archival data, this capacity is a dramatic improvement over the 3.5M bytes per cubic inch that tape storage offers (90M bytes per 10½-in., 9-track reel). Because optical disks have random-access memory, you can also access individual files or records much faster than you can with a tape, which is sequential in nature.

Another important benefit of rewritable optical disks over their magnetic counterparts is their inherent reliability. The read/write heads of magnetic disks fly on an air cushion that raises them only 2 to 5 μm above the surface of the platter. They are therefore vulnerable to dust particles as small



Providing a seek time of 35 msec, *the Tahiti by Maxtor is the fastest 5¼-in. rewritable optical drive currently available.*



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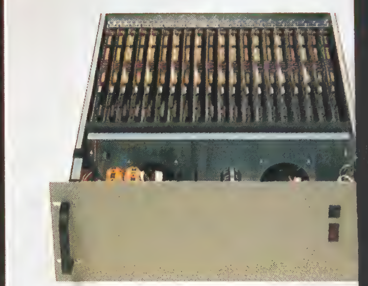

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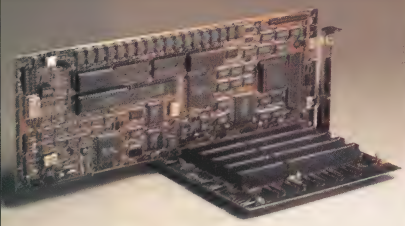
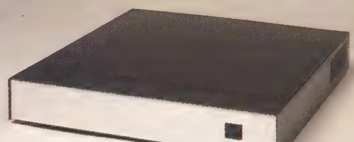
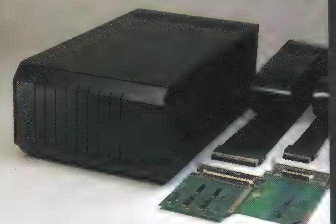


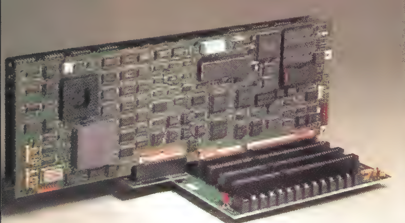
K286 PC-AT Bus 10 MHz CPU



Slim Line 4-Slot PC-AT Bus Chassis



6-Slot PC-AT Bus Expansion Chassis



H386 PC-AT Bus 16 MHz CPU with
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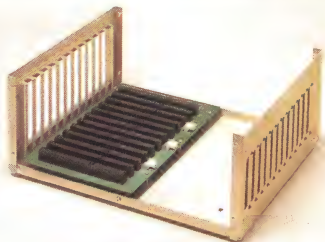
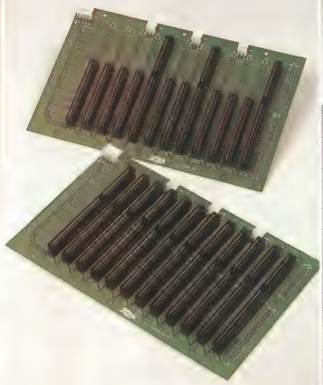


12-Slot PC-AT Bus Card Cage



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as 10 μm, which may penetrate the drive housing. Any collision with these particles (not to mention such relatively enormous objects as 80-μm human hairs) can cause the head to bounce up and down, striking and probably damaging the recording surface.

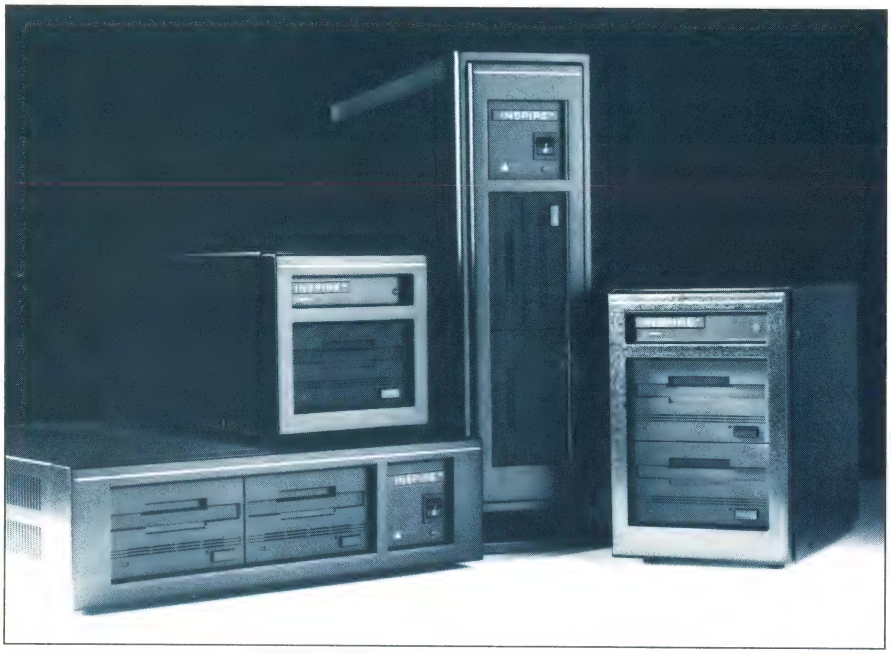
Housing makes a difference

Optical read/write heads, by contrast, are located 1000 times farther (2 mm) from the platter and are therefore not subject to the head crashes that are so damaging to magnetic-disk drives. Furthermore, rewritable disks are totally enclosed in a cartridge. The cartridge's gate isolates the disk from the environment when you withdraw the cartridge from the drive. Thus, they aren't subject to physical damage in the way that open audio CDs are.

Although the housing of a Winchester drive does provide magnetic shielding, the data stored on the drive can be damaged by very large magnetic fields. The material of an optical disk, by contrast, has to be raised to its Curie temperature (100°C or more) before the magnetic domains can change state. Optical storage is therefore much less vulnerable than magnetic storage to stray magnetic fields.

The exact life of the medium isn't known, but Dr Gordon Knight, director of optical programs at Maxtor, says that the life of these optical units appears to be infinite. Many vendors have subjected rewritable disks to 10 million erase-write cycles without any detectable degradation of the data. Media vendors guarantee their disk drives for 10 years, though the units may last as long as 50 years.

In addition to the ability to retain data for a long period of time, the fact that optical disks are removable also makes them a reliable storage medium. You can physically transport rewritable optical-disk cartridges from one system to another or to archival storage vaults. The advantages of transportability are obvious: If an organization has several workstations, a malfunction in one won't preclude access to that system's files—you can take the disk(s) to another, functional system and continue your work. Likewise, you can carry an optical-disk cartridge to a remote location and display image files to colleagues or customers. You don't need to spend time obtaining a plot or a printout until the image is in its final form.



***The Inspire Series of rewritable optical-disk drives** from Alphatronix operates with Sun, DEC, and IBM PC/AT workstations. Each drive provides 650M bytes of storage and lets you daisy-chain units to store as many as 4550M bytes.*

Furthermore, if your files contain sensitive data, you can easily remove and lock up the disks for security purposes. Many organizations that deal with classified data currently have to arrange for all their workstations' hard-disk drives to be removable so that the drives can be locked up when not in use. Because an optical-disk cartridge takes up far less space than a complete hard-disk drive, you can fit them in a relatively small safe.

The American National Standards Institute (ANSI) and the International Standards Organization (ISO) are working to establish standards for the physical characteristics of rewritable optical disks. According to Dr Knight, the ISO has adopted most of the recommendations of US and Japanese manufacturers. Media manufacturers (of which there are now about 20) are also working to ensure that their products conform to the ANSI/ISO standards for 5¼-in. drives. According to these standards, each cartridge will yield 650M bytes of formatted storage. Similarly, most vendors of 5¼-in. drives have accepted these standards. So far, though, the committees haven't developed any standards for 3½-in. drives or for the file structures of rewritable disks.

Dr Knight says that Hewlett-Packard and other Maxtor customers have been conducting interchangeability tests on 5¼-in. units. The results indicate that compatible drives conform closely to the stan-

dard, and that a disk written by one drive can be read by any other compatible drive, regardless of the sources of the medium and the drives. However, Jerry Boudreau, vice president of marketing for Hitachi America Ltd, points out that drive production is still in the pilot stage. He foresees that when vendors start ramping up to full capacity, differences between manufacturing processes and tolerances may require some adjustments to the standards to ensure reliable disk interchangeability between all compatible machines. Knight predicts that within a year or two you'll be able to transport optical disks between compatible drives with complete confidence in the integrity of the data.

Providing a 30-msec seek time, *the TMO System 35/60 by Verbatim challenges Winchester performance. It stores 60M bytes on a 3½-in. cartridge.*

Deliveries already started

Alphatronix, Hitachi, Maxtor, and Sony have started delivering compatible 5¼-in. drives that conform to the ANSI/ISO standards, and Sharp expects to have one ready later this year. Canon offers 5¼-in. drives, but, like Verbatim's 3½-in. drives, they don't conform to the established standards.

The Alphatronix Inspire system operates with Sun, DEC, and IBM PC/AT workstations, and has an average seek time of 83 msec. The Sun version has a SCSI interface that allows the optical subsystem to operate under the Sun-OS operating system. Two versions of the vendor's Rapidstore software let you interface the units to the DEC Q bus or Unibus machines. The IBM PC version comes with drivers for MS-DOS and PC-DOS versions 3.1 through 3.3. Prices start at $7900 for a single-drive PC unit. Dual-drive units are also available. Both the single- and dual-drive versions allow you to daisy-chain additional units to an existing system if you need more storage.

Hitachi's OD112 drive has an average seek time of 75 msec and a built-in SCSI interface that provides a data-transfer rate of 1.5M bytes/sec in burst mode. Hitachi also offers library configurations that contain multiple drives and yield a 300G-byte max capacity. In sample quantities, the OD112 costs $5000.

Maxtor's $5995 Tahiti I drive has an average seek time of 35 msec. The built-in SCSI interface yields a data-transfer rate of 4M bytes/sec in burst mode, and supports the SCSI Common Command Set (CCS-4B).

Sony's 5¼-in. rewritable drive has an average seek time of 95 msec, which is slightly slower than its competitors. However, many OEMs might select these subsystems because of their rugged construction and high reliability. The unit's SCSI controller can handle two drives and provides a modified ESDI interface to the drives. The controller has an onboard buffer with a 64k-byte capacity and can transfer data between the host and the controller at 1.2M bytes/sec in burst mode or 680k bytes/sec in sustained mode. The D501, which sells for $4650, is the same size as a 5¼-in. Winchester drive. It can fit in your computer without any modifications. You can also obtain the same drive as a stand-alone unit with its own power supply. The configuration (the S501) costs $5250. Both prices include the C501 SCSI controller.

Canon's 5¼-in. drive, which is the main storage unit of Steve Jobs's NeXT computer, uses a proprietary medium that has two magneto-optic layers instead of the single layer specified by the ANSI/ISO standards. The first layer, which has a low Curie temperature and high coercivity, provides fast erasure and writing. However, because of its small Kerr rotation angle, its reading performance is poor. The other layer, which is quantum-mechanically exchange-coupled to the first layer, has a high Curie temperature and low coercivity. It has a larger Kerr rotation angle than the first layer and provides superior reading performance. The drive writes to the first layer and reads from the second layer (which acquires its magnetization by exchange-coupling from the first layer). This unit, which costs approximately $6000, has an average seek time of 80 msec. Its built-in SCSI interface yields a sustained data-transfer rate of 1.5M bytes/sec.

Verbatim's TMO System 35/60 is

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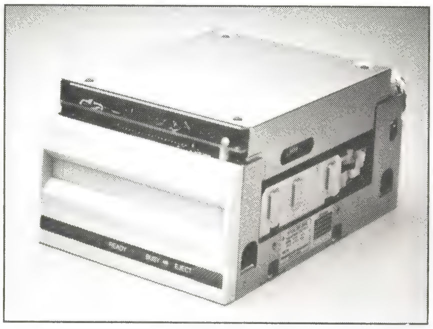
a 3½-in. drive that provides 60M bytes of formatted storage and has an average seek time of 30 msec. The built-in SCSI interface provides a sustained data-transfer rate of 1.5M bytes/sec and supports the asynchronous subset of the SCSI II command set. An evaluation unit costs $3000.

Applications are archival

Gene Bowles, vice president of marketing at Storage Dimensions Inc (San Jose, CA), believes that the current applications for these rewritable optical disks are mainly archival. However, optical units may also be used as file servers for local-area networks and shared databases if high access speed isn't crucial. Although tape is now the principal backup medium for these applications, Bowles points out that the improvements in tape technology haven't kept pace with those in Winchester technology. As a result, the greater speed and smaller bulk that optical storage offers may soon challenge tape as the principal archival medium.

In many archival applications, though, rewritable optical storage may not have a clear advantage over WORM storage: WORM storage provides permanency. However, you may have to perform a considerable amount of programming to incorporate WORM access methods into your current operating system. The rewritable units, on the other hand, can be treated like any other random-access device; you may not even have to write special drivers, because many of them have built-in SCSI interfaces that respond to a standard set of high-level commands.

Both WORM and rewritable technologies yield performance and space advantages over tape in certain types of applications. Financial transactions and shared-database operations, for example, require a clear audit trail of transactions. Likewise, scientific research often demands a long-term record of data collected from experiments for eventual analysis. These scientific applications include, for example, the telemetry transmissions of satellites and experiments on the propulsion systems of aerospace vehicles. Both types of applications produce huge volumes of data (currently stored on "tape landfill") that may take years to analyze completely. WORM storage may prove more economical for such applications.



***Featuring 650M bytes of storage** and an average access time of 75 msec, the Hitachi OD112 rewritable optical drive has a built-in SCSI interface. You can get a multidrive library configuration that can store as many as 30G bytes.*

Rewritable optical storage will probably be preferred to WORM storage in medical-imaging and image-processing applications, as well as in the banking industry. Image files and transaction records are kept for a certain length of time, but the backup or archival media is eventually rotated in a regular cycle to reduce operating costs.

Winchesters yield more speed

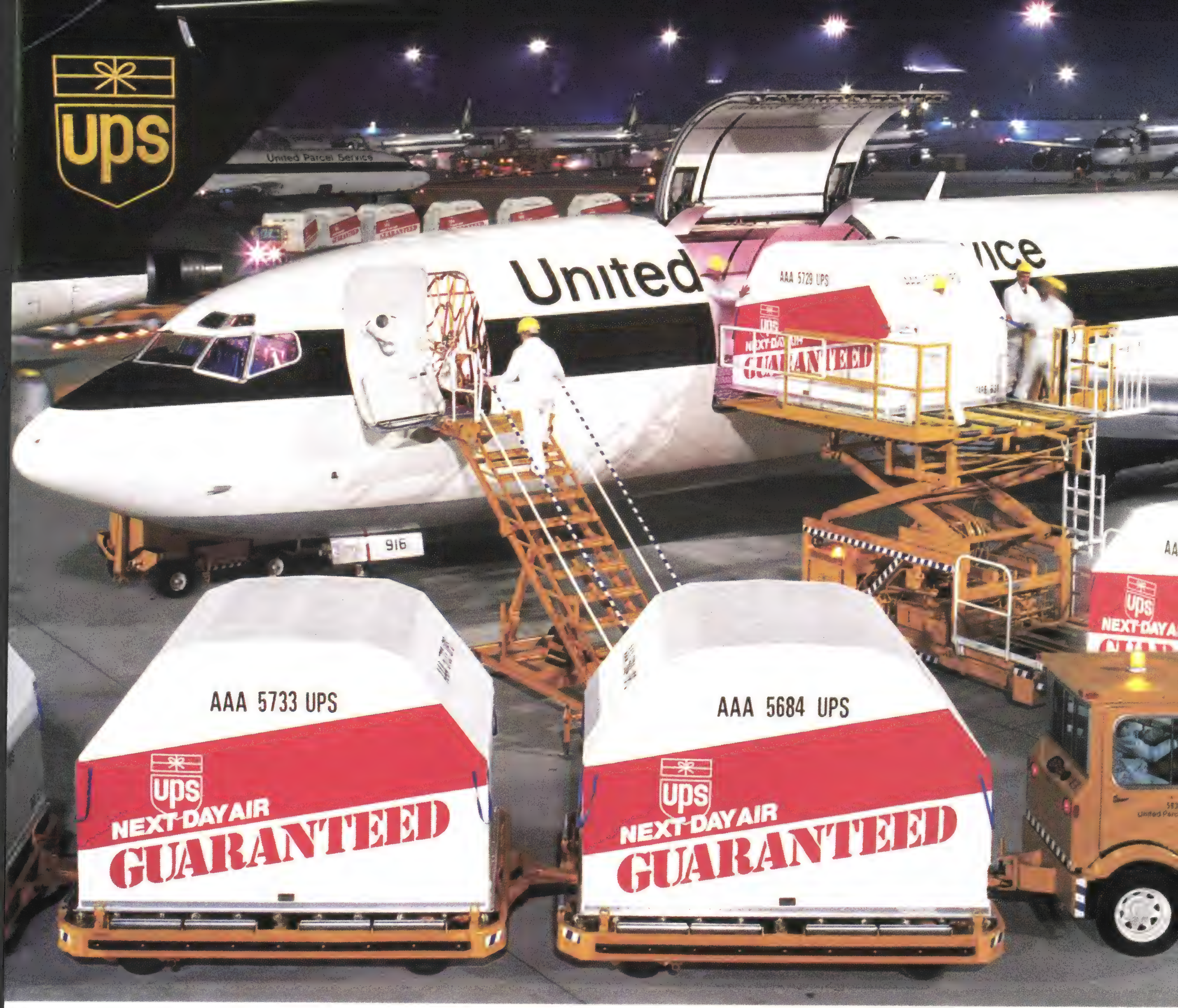
When applications demand fast, on-line access, however, hard disks are the logical choice—most large-capacity hard-disk drives have average seek times of 25 msec or less. Maxtor offers a 350M-byte drive that even has a seek time of 15 msec. Many optical drives, by contrast, have an average seek time of around 70 msec, which is too slow for multiuser or file-server applications. Slow speed isn't a characteristic of all optical drives, though. Verbatim specifies that its TMO System 35/60 has an average seek time of 30 msec, and Maxtor boasts an average seek time of 35 msec for its Tahiti rewritable drives.

The optical drives' relatively slow speed is due to the fact that their magneto-thermal technology requires two separate passes to rewrite data. In the first pass, a complete physical sector is erased and replaced with all zeros. You then have to switch a bias field or rotate a magnet (which is a relatively slow process) in order to allow the second (rewrite) pass to write the logical ones of the new data. Unlike Winchesters, which allow you to rewrite a logical record (even if it occupies only a small part of a physical sector), optical drives require you to rewrite a complete physical sector (512 or 1024 bytes)—even if you want to change only one character in one short record.

Combine optical and hard disks

Jerry Boudreau of Hitachi America Ltd believes that optical drives probably won't challenge Winchesters as the principal mass-storage medium of workstations for at least a few more years. Optical drives can, however, provide a valuable complement to Winchesters. He points out that the huge amount of storage consumed by image files (7M bytes for an 8×10-in. gray-scale drawing with a resolution of 300 dpi, and 11M bytes or more for a 4-color E-size drawing) restrict the number of drawings you can store on the hard disk of an average workstation.

In an image-processing or CAD/CAM system, the hard disk just doesn't have room for all the files you may need. Repeatedly fetching files from tape isn't a viable solution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Rewritable optical-disk drives

because the tape is slow. Substituting a rewritable optical drive for the Winchester isn't very efficient either: The rewritable drive would provide adequate storage capacity, but its 70-msec seek time would impose unacceptable delays on a highly interactive system (during extensive redrawing, for example).

One Hitachi customer is developing a possible solution to this dilemma—a system that provides long-term storage for image files on rewritable optical disks. The system transfers the files to a hard disk for editing and other short-term operations and then returns the modified files to optical storage and erases them from the hard disk. Thus, the hard disk acts as a fast cache. Although you may notice some small delays when starting or terminating file operations, the full speed of the hard disk is available to you while you're working on a file. Furthermore, you don't clutter up the fast storage with huge files that you're not currently using.

Dr Knight of Maxtor believes that ongoing research will, within the next few years, yield a way of performing direct overwrite (erasing and rewriting in one pass) on optical disks and therefore increase their speed. He points out, however, that a successful method of direct overwriting won't necessarily give optical drives an edge over Winchester drives. By the time direct-overwrite techniques become available on optical drives, expected improvements in Winchester technology (such as higher rotation speed, which is being considered by a number of manufacturers) will increase data-transfer rates and capacity. As a result, Winchesters are likely to retain their performance lead over optical drives for some years yet. EDN

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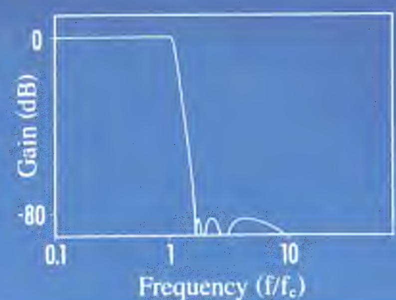

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CIRCLE NO 70

HALL-EFFECT SENSORS

Improved ICs find broad application

The potential uses for these Hall-effect-based ICs seem limitless.

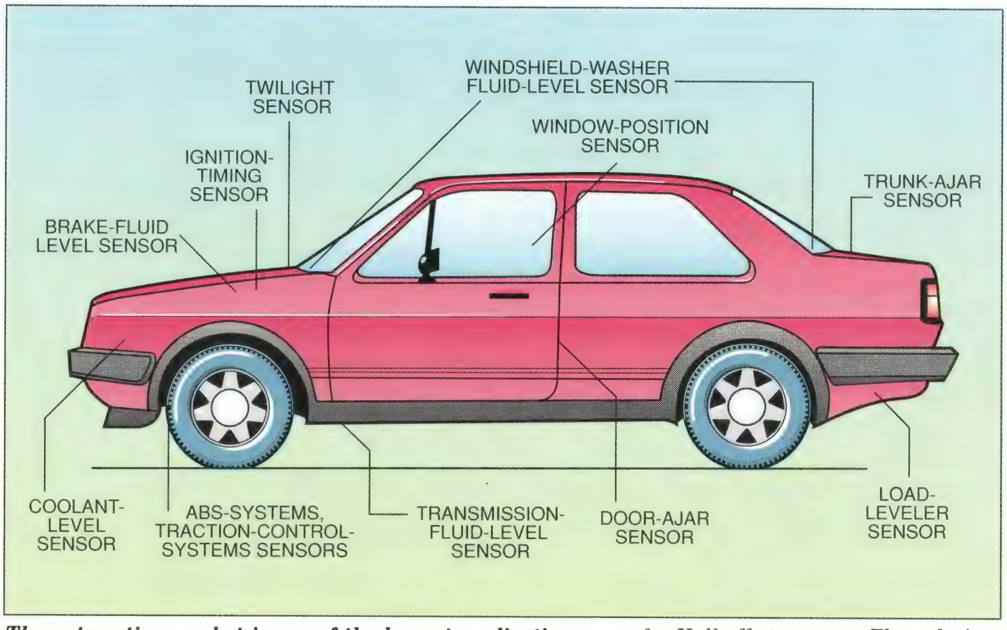
Anne Watson Swager,
Associate Editor

Improvements in reliability, sensitivity, and temperature stability have made Hall-effect sensors the transducers of choice for many applications. Whether your design involves position sensing, speed sensing, or current sensing, and whether you design automotive, industrial-control, or security systems, these Hall-effect devices offer many performance advantages over other sensing technologies.

By replacing optoelectronic devices and mechanical switches with Hall-effect devices, for example, you can create more reliable systems. Hall-effect devices are immune to dust and particle contamination, and they perform contactless, bounceless switching; they have built-in hysteresis. LEDs degrade over time and temperature, but Hall-effect devices and their accompanying magnets do not.

Further, Hall-effect sensors can operate over ever-increasing temperature ranges, such as −40 to +150°C, and they feature wide operating-voltage ranges: 4.5 to 24V. They come in both linear and digital varieties. The digital sensors can perform an unlimited number of switching operations without performance degradation. In addition, the interface between a Hall-effect sensor and its control electronics can be as simple as a pullup resistor. Finally, manufacturers can package Hall-effect devices in rugged assemblies for use in harsh and unusual environments.

Although the Hall effect was discovered more than a century ago (see **box**, "The Hall effect takes form"), no practical use was found for the phe-



The automotive market is one of the largest application areas *for Hall-effect sensors. These devices can provide stable outputs even over extreme temperatures. (Diagram courtesy Sprague)*

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nomenon until after the invention of the integrated circuit. In their initial IC form, Hall-effect sensors were costly, and they suffered from temperature-stability and reliability problems. However, advances in device fabrication over the past five years or so have improved the sensors' performance and lowered their prices. Many discrete Hall-effect sensors cost between $0.30 and $1.50 (1000); you'll pay more for

The Hall effect takes form

If you place a current-carrying conductor in the presence of a magnetic field whose flux lines are perpendicular to the direction of the current, a voltage perpendicular to the direction of the current flow develops across the conductor. The generation of this voltage—called the Hall voltage after E H Hall, who discovered the phenomenon in 1879—is known as the the Hall effect.

The basis of the Hall effect is a familiar rule of physics: The sum of all forces must equal zero. If no other forces act upon a block of N-type semiconducting material, as **Fig Aa** shows, electron flow is undistorted, and the current flow is uniform. If you apply a magnetic field, a Lorentz force causes the electrons to follow a curved path **(Fig Ab)**. This current curve causes charge to build up at right angles to the previous direction of current flow; electrons pile up on one side of the semiconductor, and holes (the absence of charge) build up on the opposite side. This buildup of electronic charge continues until the voltage across the semiconductor exactly balances the force exerted by the magnetic field. The electron flow is restored to its original undisturbed state, but now a voltage—the Hall voltage—exists at right angles to the initial current **(Fig Ac)**.

The basic Hall voltage is described by the following equation:

$$V_h = R_h(I \times B)/t,$$

where V_h is the Hall voltage, R_h is the Hall coefficient (a function of material type, and therefore of carrier mobility), I is the current perpendicular to B in amperes, B is the magnetic flux density perpendicular to I in gauss, and t is the Hall-element thickness in centimeters. This equation shows that the Hall voltage is directly proportional to the current and the strength of the magnetic field.

The practical Hall-effect devices available today make use of far more technology than these basic physical concepts. To make the devices easier to use, manufacturers equip the ICs with signal-conditioning circuitry such as voltage regulators and amplifiers. Even the basic Hall element inside each device isn't exactly *basic*: There are different varieties of the basic element, and it can be quite complex. Various geometries of the Hall element itself improve the device's performance by reducing offset voltages induced by mechanical-stress effects.

Texas Instruments, for instance, holds patents for two device geometries: the quad orthogonal Hall device and the subsurface Hall device. The quad device consists of four Hall-effect elements connected electrically in parallel; any error voltages generated tend to average out over the four devices. The subsurface Hall, also called a buried geometry, includes a protective coating, which the manufacturer applies to the top of the Hall-effect chip **(Ref 1)**. Design improvements such as these allowed manufacturers to create higher-performance Hall-effect devices.

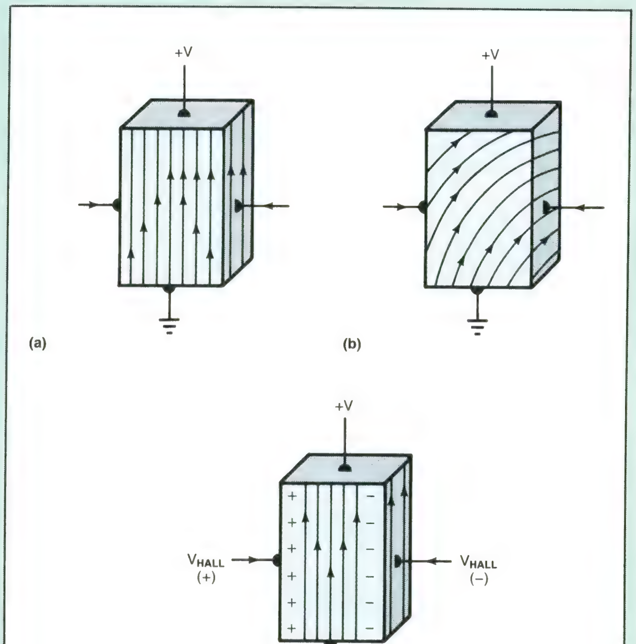

***Fig A—A constant voltage bias across a semiconductor** causes a constant current to flow **(a)**. If you apply a magnetic field, the current flow will distort **(b)**. The resultant charge buildup generates a voltage that's perpendicular to the original flow of current; this voltage is called the Hall voltage **(c)**.*

Hall-effect sensors

higher-performance or special-function devices.

To capitalize on the devices' inherent advantages and improved fabrication techniques, manufacturers produce devices with many performance and function options. You can choose from linear, switching, and latching devices. In addition to these basic functions, special-purpose devices are available: You can find such products as current sensors, vane switches, gear-tooth sensors, and a new "smart sensor" that communicates over a time-division-multiplexed 2-wire bus.

Selecting a sensor

Before you can select a specific sensor, however, you have to consider the overall system. Hall-effect devices are available with many different magnetic operating ranges and sensitivities, and you must know as much as possible about the end use of a sensor in order to pick an appropriate device. Trent Wood, applications manager at Sprague's Sensor Div, recommends that you follow these system-design steps:

- Define the application
- Select the magnet
- Select the Hall-effect device
- Design the pole pieces and targets
- Optimize the system.

To define the application—whether it's brushless-dc-motor design, distributor position sensing, or a home-security system, for example—you must consider the mechanical design of the system. The foremost consideration is the position of the magnet with respect to the sensor, and the distance (or air gap) between them.

These sensor and magnet positions are determined primarily by the type of activation the sensing system employs. There are three possible actuation modes: head-on, slide-by, and interrupted. In the head-on mode of operation, the magnet moves directly toward, and away from, the face of the sensor. This action is the simplest type, and is popular in pushbutton switches. The slide-by method is used more often; in this mode, the magnet slides by the face of the sensor, and an air gap of predetermined size separates the magnet from the sensor face. Slide-by actuation is typically used in brushless dc motors **(Fig 1)**.

The interrupted actuation mode is the most accurate method of magnetic switching. In this mode, both the magnet and the sensor are mounted on a fixed, rigid assembly and are separated by a fixed air gap. When the space between the sensor and the magnet is unobstructed, the sensor is on. But when a metal object called a vane passes in front of this air gap, the magnetic field is deflected and the Hall-effect device turns off.

Other aspects of defining the application involve environmental and electrical specifications. You must

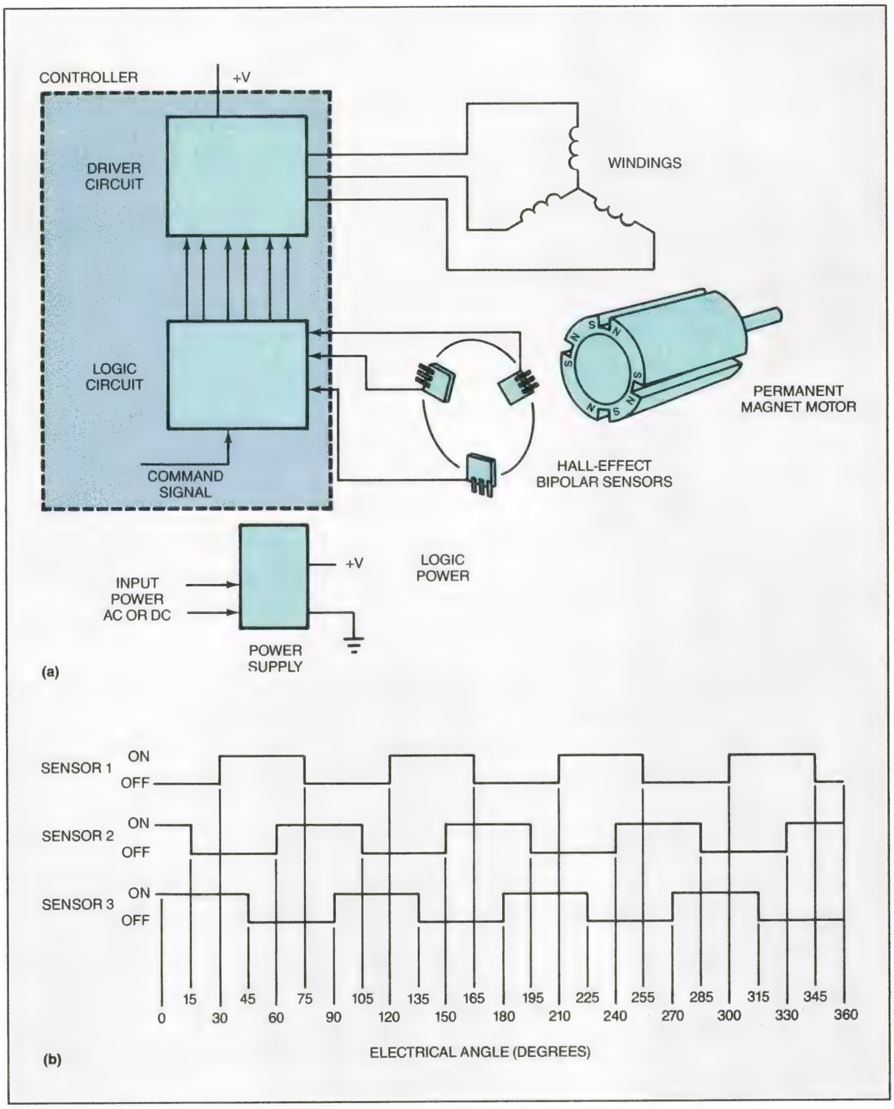

*Fig 1—**Hall-effect sensors are particularly well suited** to brushless-dc-motor applications **(a)**. As the poles of the rotating magnet slide by each digital Hall-effect device, the sensors generate waveforms **(b)**, which the controller uses to drive the motor windings. (Diagram courtesy Micro Switch)*

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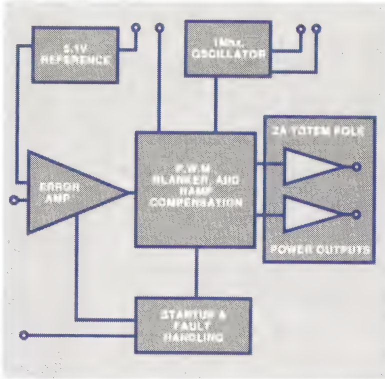
Micro Linear/Unitrode Comparison



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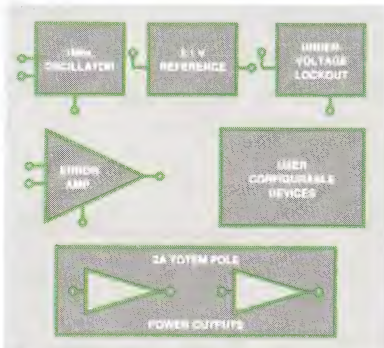

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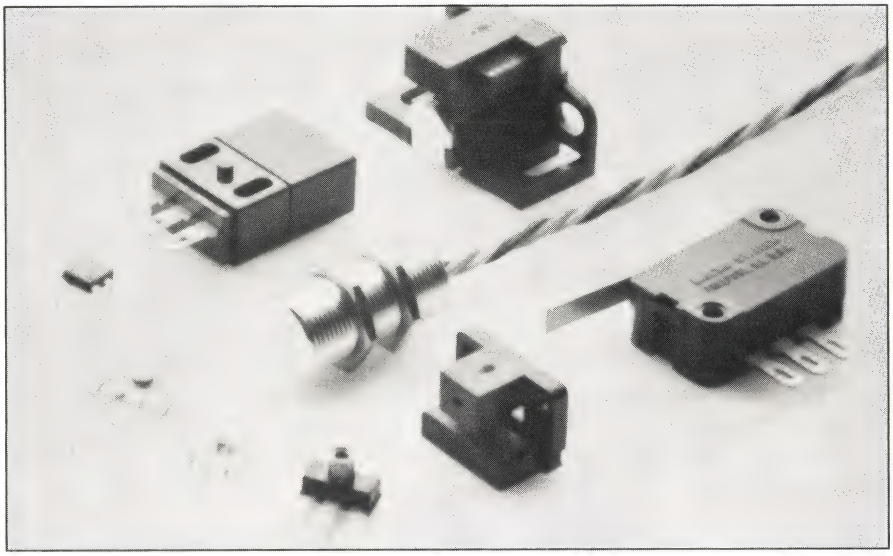
Hall-effect sensors

specify a temperature range for your sensor, and if you anticipate using a digital sensor (that is, if your application is a switching application) you need to take the desired output-waveform duty cycle into account.

The next system-design step is selecting the magnet. Specifically, you'll need to specify the magnet's material and geometric shape; the magnet's shape will depend heavily on the intended application.



***Hall-effect sensors come in a variety of shapes** and sizes. Many varieties of discrete ICs, such as these from Micro Switch, are available in 3-pin SIPs, 4-pin SIPs, and small DIPs. In addition, you can purchase a sensor packaged in a rugged housing.*

The sensor level

When you've completed these first two system steps, you're ready to pick a specific device. Sprague's Sensor Div and Micro Switch, a division of Honeywell, carry the widest lines of Hall-effect sensors, but the two companies are by no means the only semiconductor manufacturers in the Hall-effect business. Many other well-known semiconductor manufacturers also make Hall-effect devices (see manufacturers list on pg 92).

All Hall-effect ICs share some basic circuitry; the ICs incorporate a Hall sensing element with other signal-conditioning circuitry on a single silicon substrate **(Fig 2)**. One major IC component is a differential amplifier. The Hall-element output-voltage levels are quite small—on the order of µV. A low-noise, high-input-impedance amplifier produces output signal levels compatible with other system electronics. A voltage regulator or reference is also a common design feature. Most of the sensors rely on a constant current to ensure that the generated Hall voltage is only a result of the changing magnetic field. There are some exceptions to this type of measurement. Optek Technology designs Hall devices that provide a constant bias voltage and internally measure the Hall current; the overall output is still a voltage signal.

In addition to the on-chip circuitry, these Hall-effect devices share similar package styles. The most common discrete-sensor-IC package style is either a 3- or a 4-lead plastic SIP, but some sensors do come in small DIPs. Some of the special-purpose switches are available in complete rugged assemblies.

Many different types of Hall-effect ICs are variations of the circuit presented in **Fig 2**. It's best to review the devices along their lines of classification: linears, switches, latches, and special-purpose sensors such as vane switches, gear-tooth sensors, and the new multiplexing device.

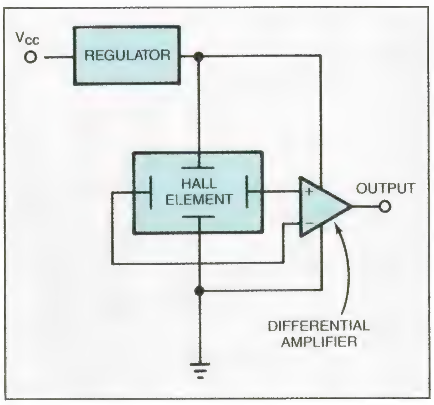


***Fig 2—Most of the Hall-effect ICs popular today** incorporate the basic Hall sensing element along with an amplifier and regulator on a single silicon substrate.*

The linear devices do exactly what you'd expect; the Hall voltage varies linearly with the intensity of the applied magnetic field. The architecture of most linear devices is almost identical to that shown in **Fig 2**. Most linear sensors have single-ended emitter-follower outputs, but both Sprague and Micro Switch offer devices with differential outputs.

So that you can power these linear devices from a single power supply, the ICs' design includes an internal, null-voltage output bias. The bias value, typically close to $V_{CC}/2$, appears at the output when no magnetic field is present. When the sensor detects a positive magnetic field, the output increases above the null value; when it detects a negative magnetic field, the output decreases below the null value, but still remains positive. (Note: in this industry, positive magnetic flux is associated with a magnet's south pole and negative flux is associated with its north pole).

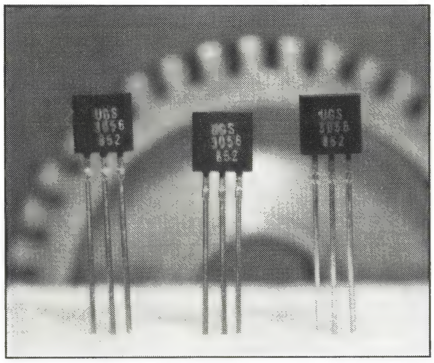
The magnetic field strengths over

Hall-effect sensors

which the sensors' linear operation is guaranteed are typically hundreds of gauss. A typical output level is that of Sprague's UGN-3501 family: 420 mV at 300 gauss. At some high magnetic field, the output will no longer be linear because the output stage will saturate; the Hall element itself will not saturate. Thus, large magnetic fields will not permanently damage the device, but merely drive it into saturation.

Some important specs for the linear devices include sensitivity, operating-temperature range, supply-voltage range, and frequency response. Typical sensitivities range from 1.3 mV/gauss for Sprague's UGS-3503U ($1.19) to 5 mV/gauss for the Micro Switch SS94A1 ($5.48). The SS94A1 design includes laser-trimmed thin-film and thick-film resistors to minimize the sensitivity variations and to compensate for temperature variation. The SS94A1's sensitivity varies from its value at 25°C by only ±0.02%/°C over the device's entire operating-temperature range. The temperature ranges of linear Hall-effect devices differ; the UGS-3503 operates over −40 to +125°C, Texas Instruments' TL3103I ($1.29) runs over −40 to +85°C, and the SS94A1 operates over −40 to +125°C. (Sprague offers many of its parts in two temperature ranges; -UGN parts have the narrower temperature range, -UGS parts, the wider one.) The typical supply voltage is 12V, though the minimum supply level can be as low as 4.5V and the maximum can be as high as 16V. The typical frequency response of these devices is in the kilohertz range. For instance, the UGS-3503 has a flat response to 23 kHz, and the TL3103I has a typical frequency response of 100 kHz.

Some linear sensors allow you to determine certain performance aspects. The Siemens TLE 4910G and



Gear-tooth sensors are specifically designed *to sense alternating magnetic fields generated by the passage of ferromagnetic gear teeth. The 3056U from Sprague (shown) and the Siemens TLE 4920G (not shown) operate to 0 rpm at large distances from a magnet.*

4910K ($0.85) are 8-pin small-outline DIP and 9-pin Micropack linear sensors that allow you to use external circuitry to adjust the bias point and sensitivity. These devices feature typical sensitivity of 3 mV/gauss and operate over −40 to +135°C (4910G) and −40 to +150°C (4910K).

Linear Hall-effect sensors represent only a small portion of the application market. Linear-sensing systems require very precise design of the magnetic interface, and users prefer to use the more straightforward switching and latching devices for that reason. Nevertheless, linear sensors are widely used as current sensors, and they're often employed in other applications to sense relatively small changes in magnetic fields.

Digital Hall-effect sensors, on the other hand, have captured the majority of the market. The internal IC designs of the digital versions differ somewhat from their linear counterparts **(Fig 3)**. In place of the emitter-follower outputs, they provide open-collector (current-sinking) or open-emitter (current-sourcing) output transistors. A digital Hall-effect sensor also includes a Schmitt-trigger threshold detector with built-in hysteresis, which prevents switching noise and oscillation. The digital sensors are divided into two categories: switches and latches. The switches can be unipolar or bipolar.

A unipolar Hall-effect switch responds to only one pole of a magnet—usually the south pole. The Hall device typically turns on when it senses a field of particular strength and turns off when the field strength falls below a certain value. The trigger points for these events are known as the operate point (OP) and the release point (RP).

A typical unipolar switch's output is illustrated in **Fig 4**. Note that as the RP changes level, the duty cycle varies. The data sheets for unipolar switches list maximum, typical, and minimum field strengths for both the OP and the

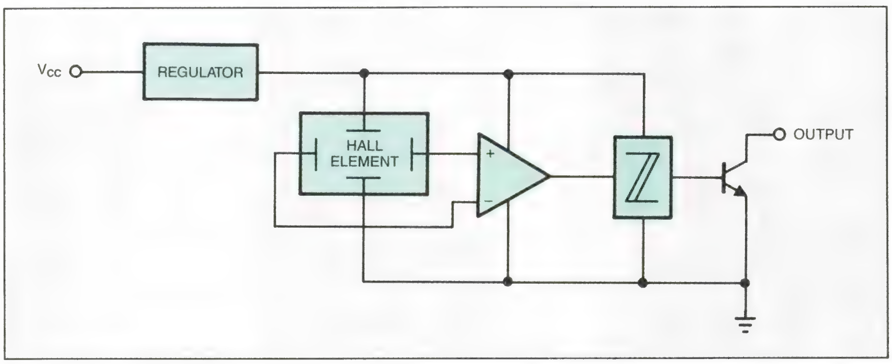


Fig 3—A Schmitt trigger and an open-collector *output are standard features of digital Hall-effect sensors. Requiring just a single pullup resistor, these devices typically drive six to 10 TTL loads.*

TURN TO PAGE 280

Hall-effect sensors

RP. The maximum OP spec and the minimum RP spec are the field strengths at which the manufacturer *guarantees* on/off operation, but any individual device may switch within the range between maximum and minimum values. Therefore, the duty cycle of a unipolar switch's output won't be 50%. Although manufacturers don't specify the exact switch point of a particular device within the maximum and minimum values, they do guarantee a minimum amount of hysteresis to ensure bounceless switching properties.

The typical field strengths required to activate the unipolar switches are in the range of hundreds of gauss. For instance, the Optek Technology OH360 ($1.11) features a maximum OP of 465 gauss and a minimum RP of 120 over −55 to +150°C; the OH360 guarantees minimum hysteresis of 50 gauss.

A bipolar Hall-effect switch is similar to the unipolar type, but its maximum OP is positive, and its minimum RP is negative. Again, these are the extreme points where switching action is guaranteed. The part's true operation may be closer to the typically quoted values, which may not require a change in field polarity. For instance, the typical values may all be positive. As with the unipolar switch, you can't guarantee a 50% output duty cycle. The typical field strengths that these devices detect are also in the range of hundreds of gauss. For instance, the low-cost TL170C ($0.31) from TI has a maximum OP of 350 gauss and a minimum RP of −350 gauss over its 0 to 70°C operating temperature range.

In addition to the unipolar and bipolar switches, you can find switches with additional features. Sprague's UGN-3235K ($0.69) and UGS-3235K ($0.93) sensors feature dual outputs that are independently activated by magnetic fields of opposite polarity (**Fig 5**). One output responds only to positive flux from the south pole of a magnet, and the other output responds only to negative flux from the north pole. The devices suit a variety of shaft-encoding and speed-sensing applications.

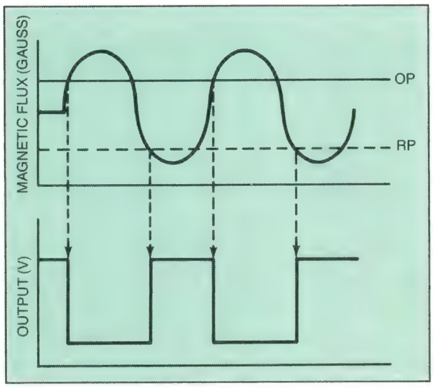


*Fig 4—**A unipolar switch reponds only to positive magnetic fields;** it turns on (goes low) when the field strength exceeds the OP and turns off (goes high) when the field strength is less than RP. Because OP and RP can vary, these devices do not generate 50%-duty-cycle outputs.*

The important specs for Hall-effect switches are similar to those of the linear devices: sensitivity (expressed in terms of OP and RP), operating temperature range, and frequency response. The typical unipolar trip points are similar to the OH360's. Bipolar devices are available with many different OP and RP ranges. The bipolar SS83CA ($1.68) from Micro Switch is one of the most sensitive switches available; it features a typical OP and RP of 15 and −15 gauss. The SS83CA operates from −55 to 150°C, and features a frequency response of 100 kHz. Optek Technology's bipolar OHS3131 ($1.35) operates from −40 to +125°C and features a maximum OP of 135 and a minimum RP of −135; output amplitude is constant at switching frequencies from dc to 200 kHz.

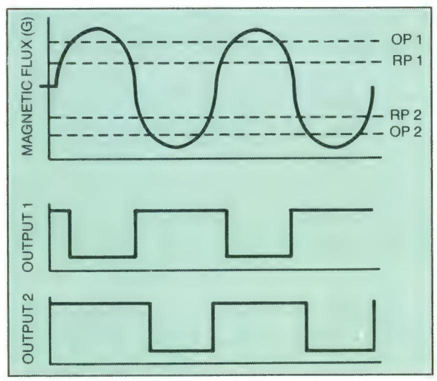


*Fig 5—**A digital Hall-effect sensor that features a dual switching function** is the UGN-3235K (or UGS-3235K) from Sprague. This device's two outputs are independently activated by magnetic fields of opposite polarity.*

The digital devices' specs also include current-sourcing and -sinking capability, time-domain-response characteristics (rise and fall times), and amount of hysteresis. The drive capability typically ranges from 20 to 50 mA, and the rise and fall times are around 1 to 2 μsec. The SS83CA and OHS3131, for instance, feature rise and fall times of 1.5 and 2 μsec, respectively. The hysteresis of the SS83CA is expressed in terms of the minimum difference between the max OP and min RP, and is specified at 5 gauss. The OHS3131 specifies a minimum hysteresis of 10 gauss.

Latches have tightest specs

Although these available Hall-effect switches and their various combinations of performance specs suit many applications, if you require a *guaranteed* output duty cycle around 50%, you'll want to consider a Hall-effect latch. The difference between the bipolar switch and the latch is a subtle one; the main distinction is that the latch has more precise control of the OP and RP parameters. Sometimes manufacturers refer to a bipolar device simply as a "true latch."

Latches turn on when the Hall element is exposed to a south magnetic pole; the output remains on even when the magnetic south pole is removed, and doesn't release

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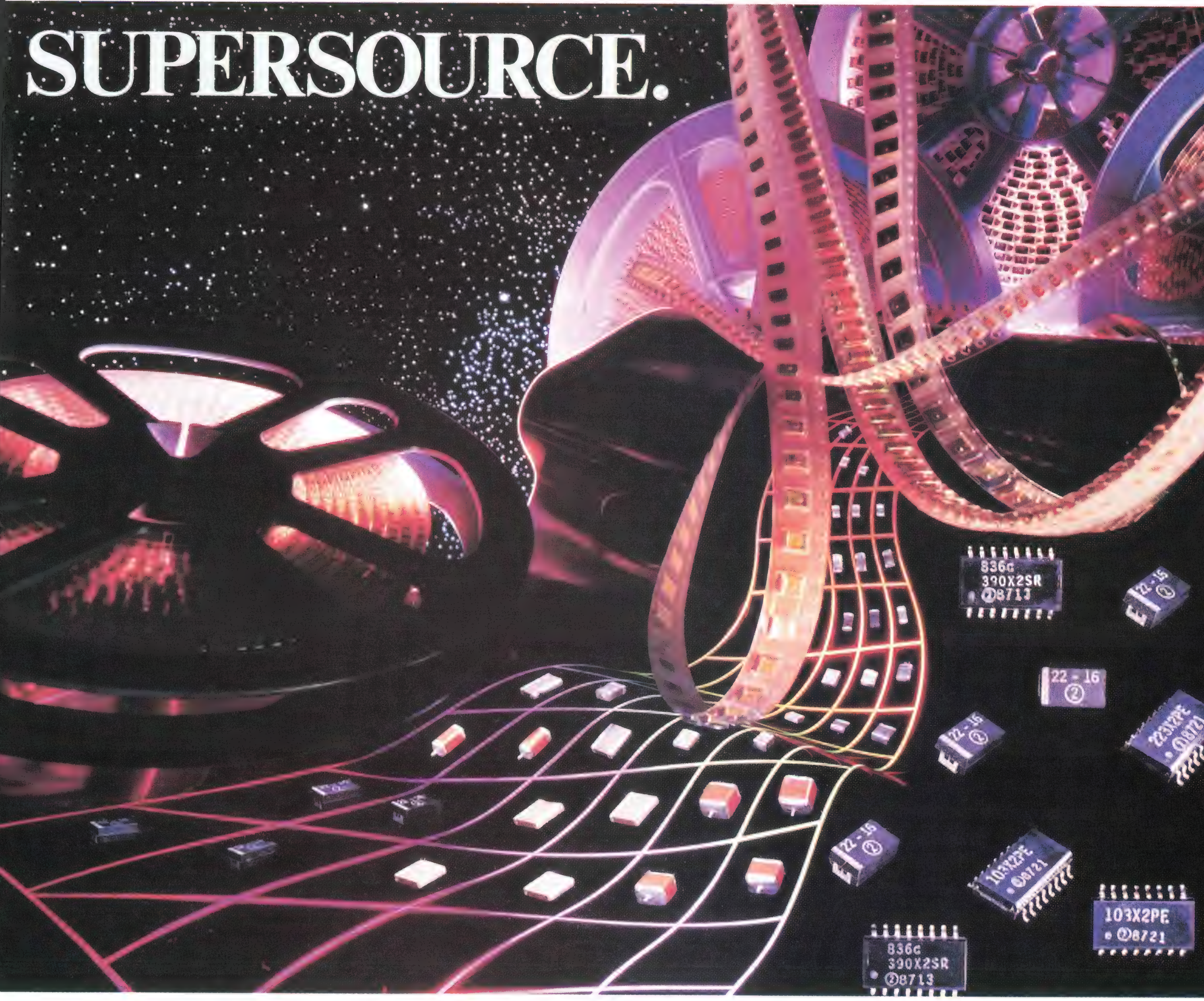

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(turn off) until a north magnetic pole is presented to the face of the sensor. In other words, this device will not switch until it senses fields of equal but opposite magnitude. You can tell a true latch from a bipolar switch by looking at the OP and RP specs. For instance, the specs for the UGS-3075 ($0.71) are completely symmetrical in nature: The max OP is 250 gauss, and the min RP is −250 gauss; the typ OP is 100 gauss, and the typ RP is −100 gauss. The min OP is 50 gauss, and the max RP is −50 gauss. Therefore, the device will turn on somewhere between 50 and 250 gauss, but it won't turn off unless it senses an opposite field somewhere between −50 and −250 gauss.

Most latches have output duty cycles very close to 50%, and you can find latches with complementary outputs. Sprague's UGS-3275K ($1.16) through UGS-3277K ($1.36) have two output transistors: one is on for fields above OP and the other is off. The reverse is true for fields that fall below the RP.

Fig 6—The CS line of miniature digital current sensors *from Micro Switch includes models that sense current from 2.6 to 15A. These devices perform in-line current sensing at temperatures from −25 to +85°C.*

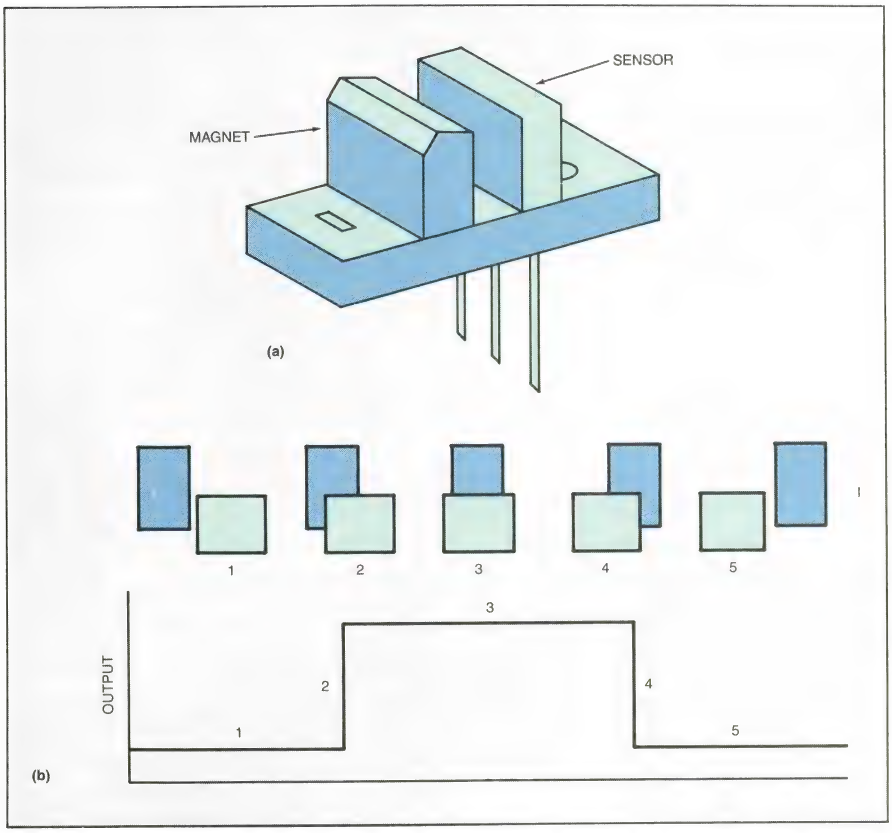

Fig 7—A vane switch implements the interrupted mode of actuation*. As the ferrous vane (not shown) passes between the magnet and the sensor* ***(a)****, the device turns on and off* ***(b)****. (Diagram courtesy Sprague)*

ICs are application-specific

Linear devices, switches, and latches are the fundamental types of Hall-effect sensors. Manufacturers modify or optimize certain parameters of these basic functions to serve specialized applications, such as current sensors, vane switches, gear-tooth sensors, and multiplexing "smart sensors.

Micro Switch's CS line of current sensors includes both linear and digital devices in a variety of assembled packages. The devices measure current by measuring the magnetic field surrounding a current-carrying conductor. The product line includes linear sensors that provide both dc and ac outputs while sensing an ac current. The series-connect digital sensor's open-collec-

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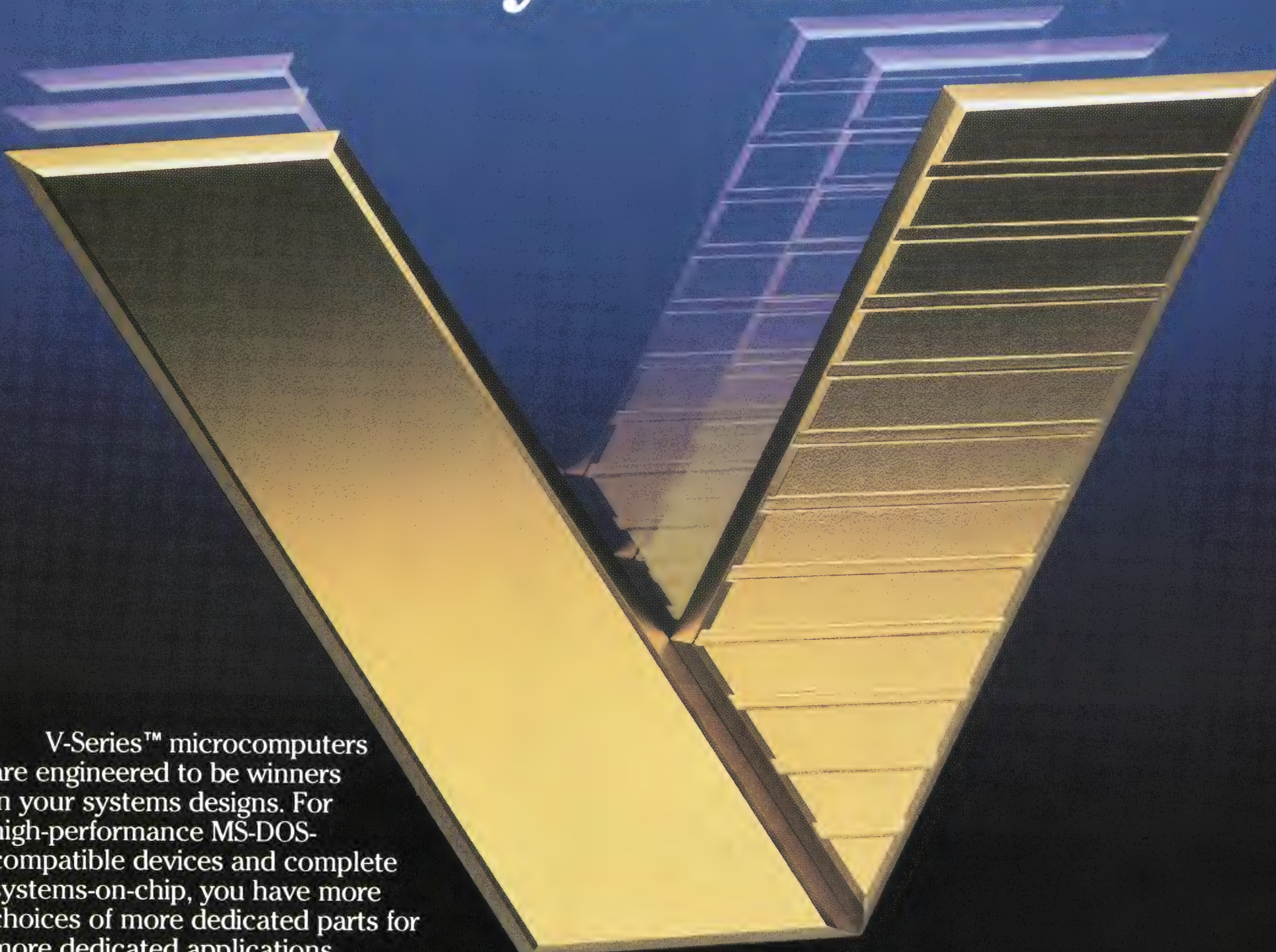

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Hall-effect sensors

tor outputs switch from the supply voltage (which can range from 4.5 to 24V dc) to 0.4V when they sense a predetermined level of current. For instance, the CSDD1ED ($11.31) digital current sensor features an operating current of 3.5A and a release current of 2.6A. Other devices in the same family feature operating currents of 5, 6.5, 9, 10, and 15A. These devices are fully encapsulated, and they can be mounted on pc boards **(Fig 6)**. These current sensors are used mainly for power verification and for overcurrent detection.

Vane switches implement the interrupted mode of actuation. The movable vane method is a practical switching implementation, because the magnet and sensor can be molded into a single rugged assembly. As long as magnetic flux reaches the sensor, the device will be on; however, as the ferrous vane passes between the magnet and sensor, it will divert the flux and turn off the device **(Fig 7)**. The operating parameters for vane switches are specified in terms of left and right release points. Vane switches are commonly used in distributors, as well as in a variety of other position-sensing applications, such as security systems, door contacts, limit switches, and safety switches.

You can construct your own vane sensor from a discrete sensor IC, or you can buy a complete molded assembly, such as Micro Switch's 1AV2A ($5.63). The 1AV2A belongs to a complete line of products that the company calls "integral magnet position sensors." They combine digital Hall-effect sensors with integral magnets in rugged plastic housings. The AV Series contains devices with either current-sinking or current-sourcing outputs at supply voltages from 6 to 24V.

Gear-tooth sensors are Hall-effect switches that respond to magnetic-field *differences* created by passing ferrous targets. Designed to sense moving targets down to 0 rpm over a wide range of air gaps and temperatures, gear-tooth sensors use two Hall-sensing elements to measure flux differences.

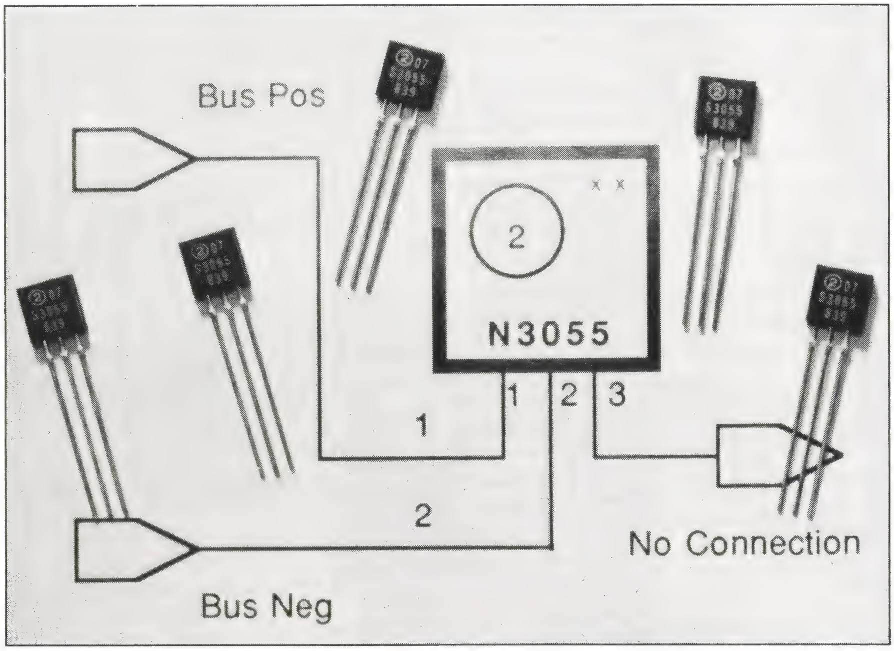


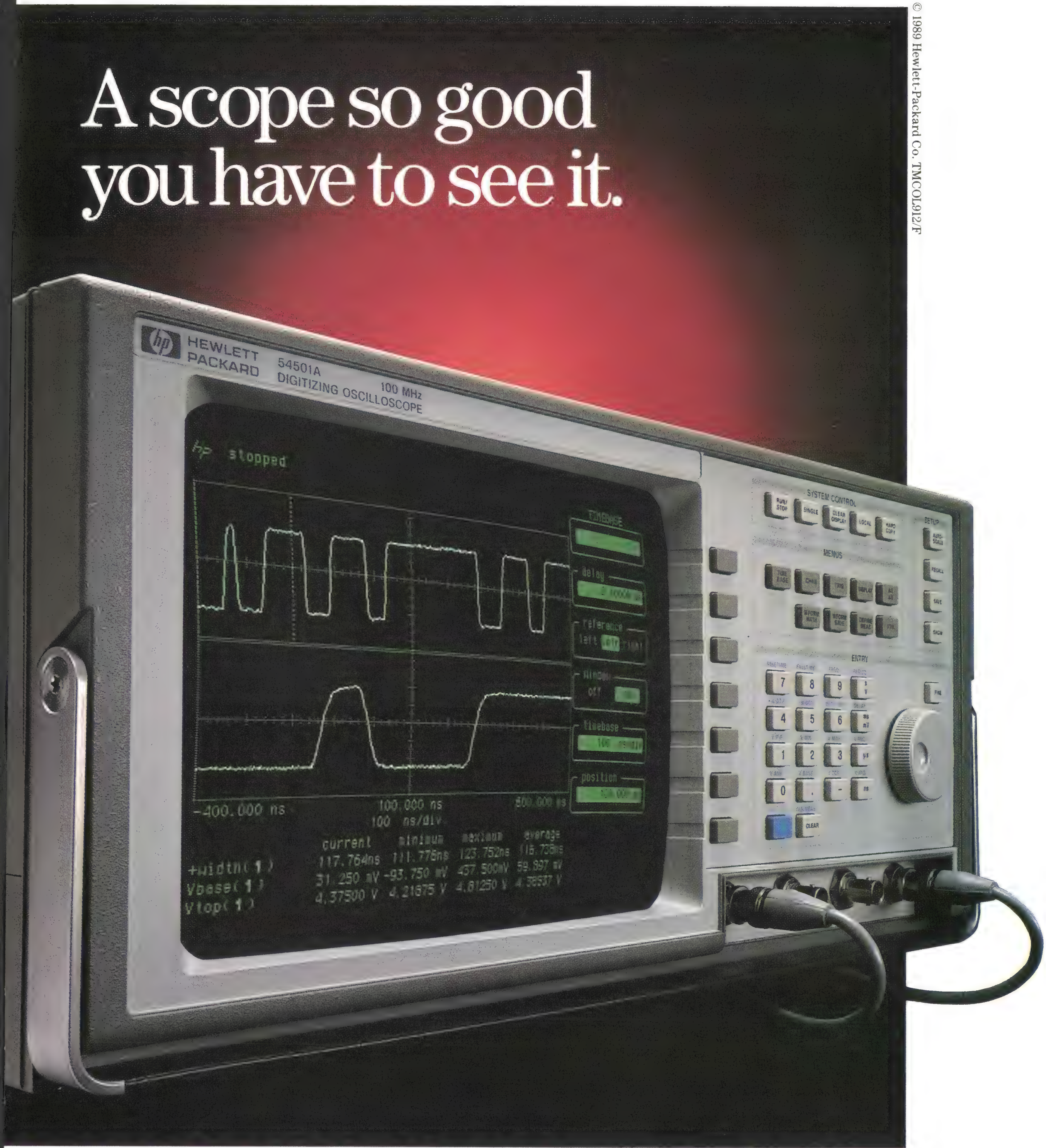
Fig 8—The newest step in Hall-effect-sensor design *is a 2-wire, time-division-multiplexing device (the 3055) from Sprague. You can string as many as 30 of these sensors together, run diagnostic checks on each device, and receive information from each sensor at a main controller site.*

Because a gear-tooth sensor measures differential flux, you can place the sensor IC farther from the gear train it will be used with. The larger air gap makes system design easier by relaxing tolerances on both the mechanical and the magnetic flux density. Over −40 to +125°C, Sprague's UGS-3056U ($1.67) digital gear-tooth sensor switches on in response to differential flux values anywhere between −150 and +120 gauss; it switches off for differential flux values between −250 and −5 gauss. The IC guarantees a minimum of 20 gauss of hysteresis, features rise and fall times of 400 nsec, and switches at rates as high as 100 kHz.

Another gear-tooth sensor, the TLE 4920G ($2.60) from Siemens, features an internal highpass filter; when you supply an external integrating capacitor, this filter helps to eliminate static offsets in the device. This digital sensor operates over −40 to +150°C and has a frequency range of 10 kHz. To accommodate external capacitor connections, the device comes in an 8-pin DIP.

"Smart sensors" emerge

Unlike vane switches and gear-tooth sensors, both of which are basic Hall devices that have been packaged or optimized for particular uses, Sprague's multiplexed sensor IC demonstrates a new step in sensor design: It has higher functional integration **(Fig 8)**. The UGN- and UGS-3055U ($1.40 and $1.60, respectively) are intended for multiple-sensor applications in which minimizing the wiring-harness size is a major design goal. In addition to its many automotive applications, the device suits security-



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systems applications. The device is the product of a cooperative working relationship between Sprague and Chrysler Motor Corp; it operates under Chrysler's patented CSC sequential-addressing scheme **(Ref 2)**.

The 3055 is a 2-wire system (power and ground bus) that uses a time-division-multiplexing scheme to send information between a controller and as many as 30 sensors at a 10-kHz rate. The master controller transmits and receives information by modulating the power-supply voltage. In turn, each sensor communicates with the controller by modifying its current drain over the bus. The controller then measures and uses this increase in bus current for further decision making.

Each sensor is preprogrammed at the factory with a particular address, and it responds during specific times of its address cycle. An increase in current drain during the high portion of the cycle tells the controller that the sensor is functional. To indicate that it detects a sufficiently strong magnetic field, the sensor simply maintains this current drain during the low portion of the address cycle.

The higher integration of this multiplexing sensor seems to be the design trend of the future. It's not simply the sensor's greater number of functions that is significant, however. The manufacturer developed this part in response to a particular customer's need—an indication that manufacturers are dedicated to providing custom as well as standard products. And regardless of whether you use a custom or a standard product, most sensor manufacturers will assist you with every phase of the design cycle, from defining the application and selecting the sensor to optimizing the system. **EDN**

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1. Hines, J R, and T P Lantzsch, "New Life for Hall Effect Sensors," *Machine Design,* October 10, 1985, pg 83.

2. Wroblewski, T, and F Meisterfeld, "Switch Status Monitoring System, Single Wire Bus, Smart Sensor Arrangement Thereof," Assignee: Chrysler Motors Corp, Highland Park, MI, US Patent Number 4,667,308, June 30, 1987.

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For more information . . .

For more information on the Hall-effect sensors discussed in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

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SERIES
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PC-BASED OSCILLOSCOPES

Units transform PCs into DSOs

Although few yet rival the performance of stand-alone instruments, these new products are winning enthusiastic support from EEs—and for good reason.

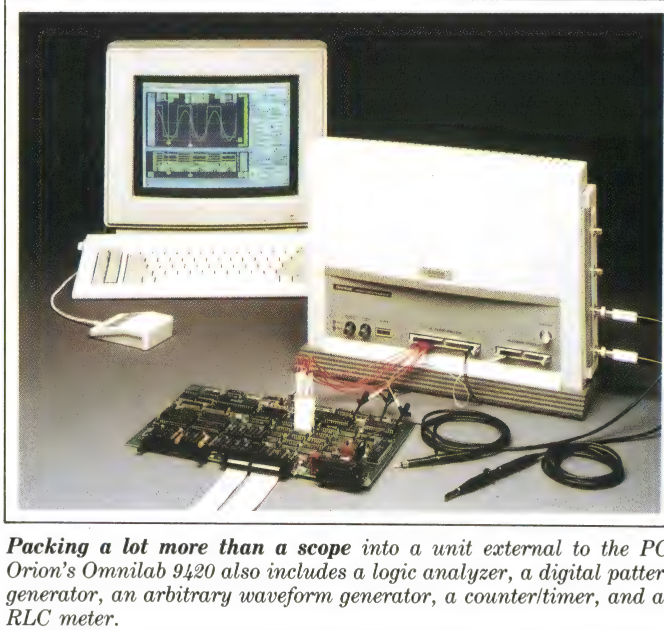
Dan Strassberg, *Associate Editor*

Few products can make electronic design engineers wax poetic. Certainly most EEs are not given to poetry when discussing the test instruments they use to get their jobs done. Yet, expansive, almost poetic descriptions of product benefits were the rule, not the exception, among a group of EEs recently contacted by EDN. These engineers were speaking about their reactions to personal-computer-based oscilloscopes—and their enthusiasm wasn't confined to a single vendor's product.

Although there are exceptions, most PC-based digital storage oscilloscopes (DSOs) can't rival the performance of top-of-the-line stand-alone instruments. If you need analog bandwidth in the hundreds of megahertz or real-time sampling rates above 40M or 50M samples/sec, only a few of the PC-based products will suit you. Furthermore, if low purchase price is your paramount consideration and you can forego the conveniences of a digital scope, you may well do better by choosing a stand-alone analog scope. But if you already own a PC, can share it among several tasks, want a DSO with mid-range performance, and are willing to spend a little time learning to operate a scope whose user interface is different from what you're accustomed to, choosing a PC-based DSO can be a very smart move.

One reason that PC-based scopes appeal to the engineers who've switched from conventional instruments is that so much software for processing, analyzing, and plotting acquired data runs on PCs. (EDN recently covered this software in depth—see **Ref 1**; a number of these packages are mentioned in **Table 1**.—See pg 110.)

You can, of course, use most of this software with instrument-level DSOs: Nearly all of them have or can be equipped with IEEE-488 or RS-232C ports that let you send acquired data to a PC. Indeed, most third-party data-analysis and -display packages provide direct support for many IEEE-488 interface boards, although, at most, the packages support only a few board-level DSOs. Therefore, using a third-party



Packing a lot more than a scope *into a unit external to the PC, Orion's Omnilab 9420 also includes a logic analyzer, a digital pattern generator, an arbitrary waveform generator, a counter/timer, and an RLC meter.*

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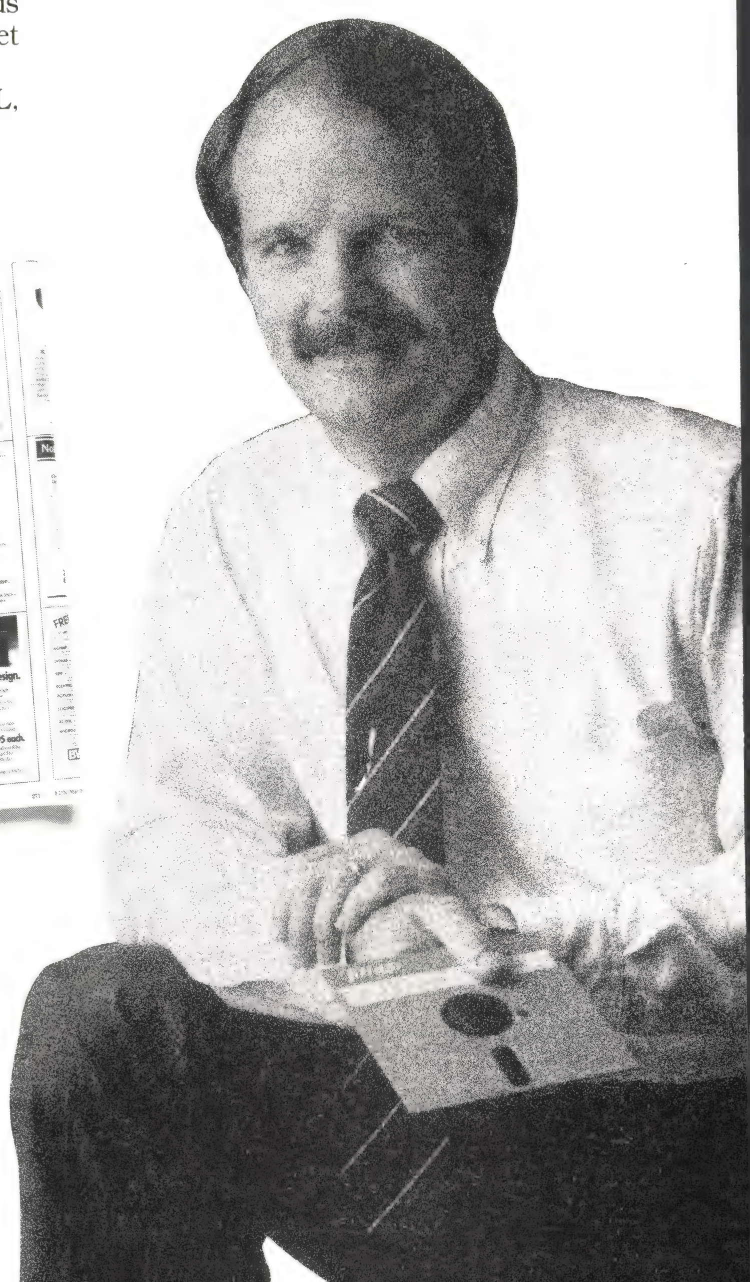

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PC-based oscilloscopes

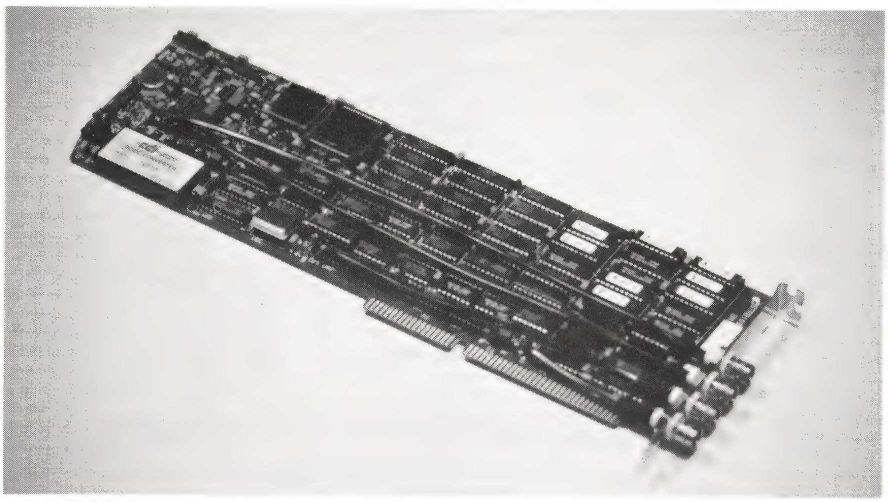
analysis/display package with a board-level DSO may require you to first store the data on disk and then load the data from disk into the software. This approach has some problems, which are discussed in **Ref 1**. Despite these problems, engineers apparently find the convenience of using the same equipment for both data acquisition and analysis tremendously appealing.

As **Table 1** reveals, the capabilities of the software furnished with PC-based scopes varies substantially. Moreover, there apparently is a trend toward adding features to the supporting software over a period of 12 to 18 months after a product's initial introduction.

For example, BitWise Designs (Troy, NY) recently reached tentative agreement to adapt its PC-based-scope software package to boards made by Sonotek (Springfield, VA) and Golem Systems (Newberry Park, CA). BitWise had originally developed the software to support hardware of its own design—hardware that it continues to sell. Golem and Sonotek realized that BitWise's software, which runs under Microsoft Windows, is more comprehensive than their own and could help them appeal to more users. For its part, BitWise recognized that by offering the Golem and Sonotek boards with its software, it could attract more customers, too.

Placing a waveform digitizer *in a chassis that can also house an 80286-based PC, Kontron's W+W 700 can sample at 50M samples/sec and can accommodate 32 channels if you add expansion chassis.*

Some vendors ship their products with rather rudimentary software—just enough to enable you to write your own control programs in a high-level language, such as C or Pascal. Because many PC-based scopes act as memory-mapped I/O devices—accepting commands you deposit in specific memory locations and placing acquired data in other locations—you may find the simple software both easy to work with and quite appropriate. You'll probably like this bare-bones approach most if you need to create a custom control program for an OEM application or if you'll be storing data and reducing it subsequently with off-the-shelf software.



Offering very high performance *in a single-board unit that plugs into the IBM PC/AT bus, Sonotek's STR*8100 takes 100M samples/sec in real time or 800M samples/sec in equivalent time.*

Other PC-based-scope vendors, such as Rapid Systems (Seattle, WA), supply software packages that let you access powerful data-reduction capabilities in real time. Some packages even go beyond waveform addition, subtraction, multiplication, averaging, and filtering. A very popular capability is computation of waveform frequency spectra using fast Fourier transforms (FFTs).

The engineers that EDN queried

for this article had reasons for enthusiasm that went beyond the software, though. Among the most-mentioned PC-based-scope characteristics were the instruments' compactness, their excellent perfomance for the price, the simplicity of storing waveforms on disk and recalling them later for analysis, and the ease of printing out waveforms on dot-matrix and laser printers. One engineer cited the ease of interpreting multiple waveforms displayed on his PC's color monitor. The PC already had a color display, so the color capability didn't cost extra. You can get color displays in instrument-level DSOs, but only in expensive, top-of-the-line models.

An economical high-speed unit *that mounts externally is Rapid System's R2000. The vendor also offers a similar-looking unit that performs both scope and spectrum analyzer functions.*

As with the PC-based logic analyzers that EDN covered last October (**Ref 2**), PC-based scopes take several physical forms and offer a wide range of performance. You can find units contained entirely on cards for the IBM PC and PC/AT buses as well as in external units that couple to the computer bus via proprietary cards. A few units, mostly waveform digitizers, interface via IEEE-488 I/O cards. Prices start at under $1000, and many units are priced below $2000. A few units that offer very high performance are available in configurations that can cost in excess of $100,000. Among the higher-performance units, most of which are fairly expensive, are products that vendors call high-speed waveform digitizers. **Table 1** includes only a few of the high-speed digitizers on the market.

A digitizer can become a DSO

Most digitizers, such as the products from LeCroy (Chestnut Ridge, NY) and Nicolet (Madison, WI) in **Table 1**, are, in fact, DSOs without a display. These instrument-level products usually mount outside the computer on a benchtop or in a rack. When coupled to a graphics-capable PC running appropriate software, such a digitizer can perform oscilloscope functions. But one of these waveform digitizers is different: Kontron (Mountain View, CA), the company that pioneered logic analyzers that include a PC, now offers a waveform digitizer that can include an 80286-based PC. It's called the Model W+W 700 transient recorder; its pricing begins at $13,000. It can capture 25-MHz signals and can have as many as 32 channels through the use of expansion chassis. The unit can store 256k samples now and, later this year, will be able to store as many as 1M samples.

Master of many trades

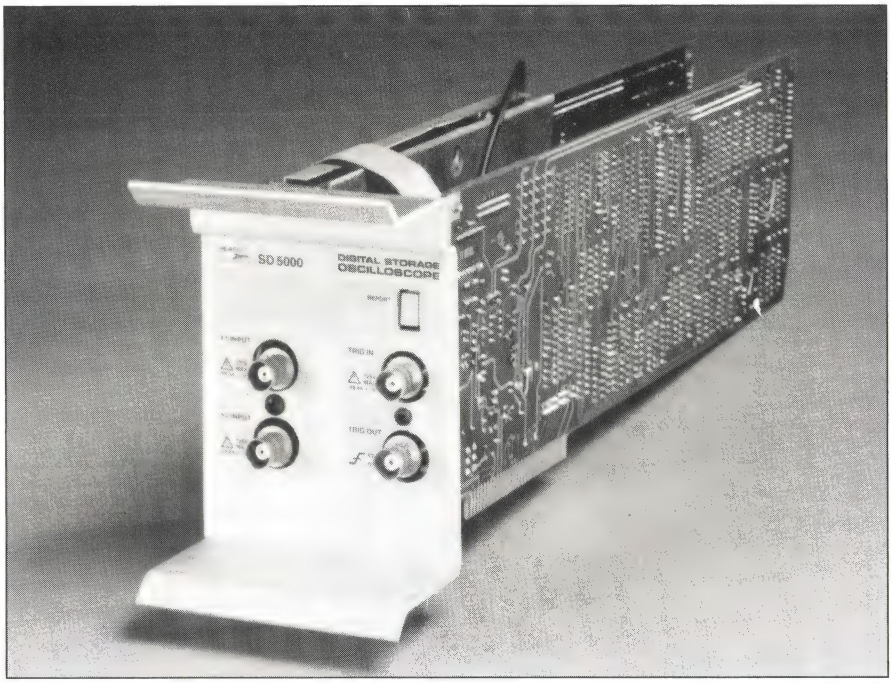
Another product with a decided difference from the others has been mentioned repeatedly in EDN articles on instrumentation over the past 18 months. That product is the $8900-base-price Omnilab 9420 from Orion (Redwood City, CA). The reason that the Omnilab turns up so frequently in EDN's instrumentation coverage is that it does so many things. Not only is the Omnilab a scope, it is also a logic analyzer, a digital pattern generator, an arbitrary waveform generator, an RLC meter, and a frequency counter. If the phrase "jack of all trades and master of none" comes to mind, take a look at **Table 1**: Orion need not apologize to anyone for the Omnilab's performance. Furthermore, users claim that the mouse-controlled windowing software is a delight.

A product that EDN *didn't* find was a hardware unit for any member of Apple Computer's Macintosh family. None of the vendors we talked with makes a Nubus-based high-speed digitizer or DSO card for the Macintosh II. There may be waveform digitizers that interface to their host CPU via a SCSI port, but we didn't encounter any. With appropriate software, such a SCSI-based digitizer would convert any Macintosh into a DSO.

For the purposes of this article, EDN asked hardware vendors to supply information on products capable of reproducing analog signals that contain frequencies of 5 MHz

PC-based oscilloscopes

and more. To properly capture a signal that contains a 5-MHz component whose amplitude is at least half the weight of its least-significant bit (LSB), an A/D converter must take at least 10M samples/sec. For nonrepetitive signals, the converter must have a *real-time* sampling rate of 10M sample/sec; for repetitive signals, the 10M sample/sec rate can be either the real-time or the *effective* sampling rate. Failure to sample often enough will introduce spurious "alias" frequencies into the data; without some additional information about the nature of the signal, you can't separate the aliased information from real data.

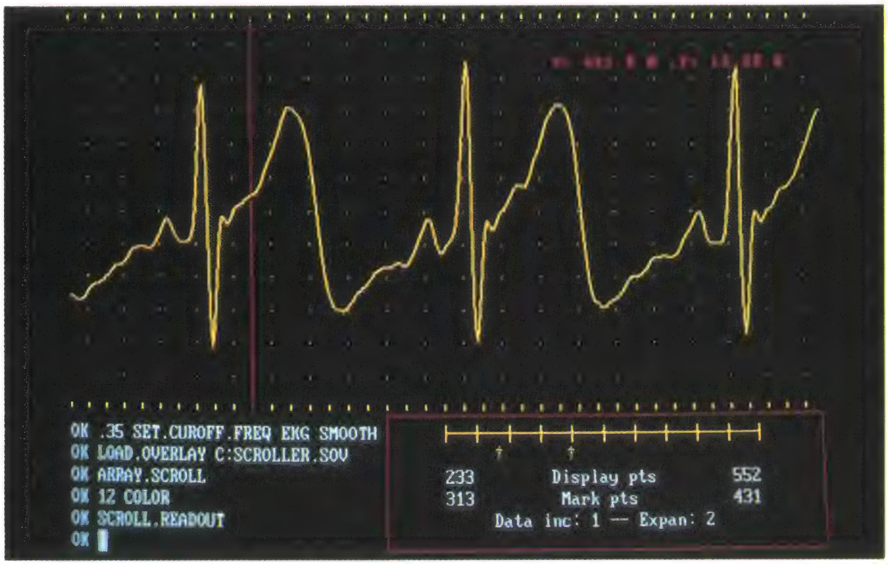


***Another approach to packaging** a PC-based DSO is represented by the SD-5000 from Heath/Zenith. Its two cards can plug in within the PC; or, with the optional panels shown here, you can house it in the vendor's chassis that replicates the computer's bus.*

Recurring signals ease sampling

If the analog signal is repetitive, the ADC need not take every sample during a single occurrence of the waveform. Instead, it can take samples spaced rather widely in time and "fill in" the points it has missed by sampling when the waveform repeats, thus creating a higher effective sampling rate.

This technique, known as "equivalent-time" sampling, can be implemented in two ways. In sequential equivalent-time sampling, each successive sample is taken later within the incoming waveform than was its predecessor. If the waveform duration is 1 μsec and you're sampling at an effective rate of 100M samples/sec, the ADC might capture the second sample 1.01 μsec—or 2.01 μsec—after the first. In random equivalent-time sampling, the samples occur more or less at random within the waveform; a controlling microprocessor keeps track of the position of each sample and presents the samples in the correct order during a display.



***Data-analysis software packages** that work with data acquired by PC-based scopes offer many useful features. The software package called Asyst, from Asyst Software Technologies, provides a detailed view of a brief segment of a long waveform.*

Each of these equivalent-time sampling techniques has areas where it excels. Sequential sampling is capable of the highest bandwidths. Random sampling provides the greatest flexibility in viewing pretrigger data.

Several of the units discussed here employ equivalent-time sampling, but the technique is not quite as common in PC-based scopes as it is in instrument-level DSOs. Furthermore, sequential sampling is more popular than random sampling in PC-based DSOs; the opposite is true in instrument-level products. Those PC-based scopes that use equivalent-time sampling don't normally use it to permit

viewing signals as slow as 5 MHz. Rather, for reasons explained below, they employ the technique to improve the detail of displayed features of repetitive waveforms that contain frequencies near the units' analog-bandwidth limits.

Two samples/cycle aren't enough

Many readers will probably be surprised to learn that regardless of the sampling technique, you can't get a good time-domain picture of a signal by sampling at a rate only equal to twice the frequency of the fastest component whose amplitude is at least ½ LSB. Although such a sampling rate can be acceptable for frequency-domain analysis, to reproduce the edge of a pulse with reasonable fidelity you need to take at least three samples during the signal's rise or fall. To reconstruct a sine wave, you need to sample it at least four times per cycle. If the waveform is repetitive, however, and you use equivalent-time sampling, you can acquire the samples during the course of multiple waveform occurrences.

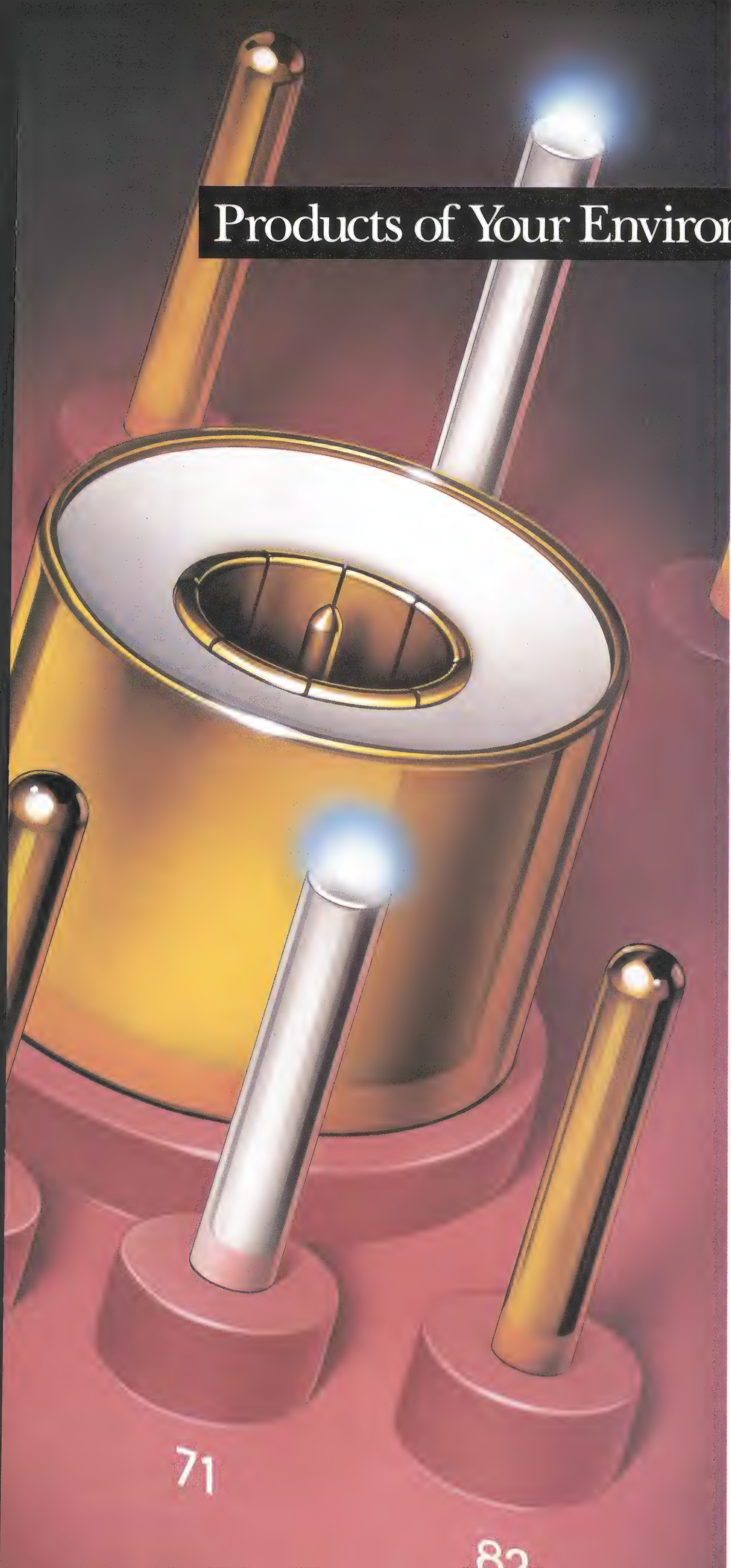
Another widespread misconception about DSOs relates to the techniques they can use to filter out input-signal frequency components that would otherwise produce aliasing. The analog filters usually used to reject such high-frequeny signals can represent a major component of the cost of a DSO or waveform digitizer (**Ref 3**). A seemingly good solution to this problem is using digital filtering instead of analog filters. However, unless you have a knowledge of the signal characteristics that you normally don't have, once aliasing has corrupted the data, you can't employ any kind of filtering to restore the data.

A technique called oversampling—sampling at many times the highest frequency present in the input signal—allows the use of digital filtering in conjunction with relatively simple and inexpensive analog filters. The problem with oversampling is that it requires a much faster ADC (or, if you use equivalent-time sampling, significantly longer data-acquisition time) and a deeper and more costly waveform memory than you would otherwise need.

Today, few DSOs use oversampling because of the size and cost of the extra high-speed memory and because the high-speed, high-resolution converters required are either prohibitively expensive or completely unavailable. However, ADC technology is constantly improving and converter manufacturers continue to lower product costs and introduce faster converters. And despite temporary reversals of the downward price trend, memory continues to become more dense and less expensive. As a result, you can expect to see oversampling become increasingly popular in DSOs and waveform digitizers, both those based on PCs and those that stand alone.

As already suggested, conversion speed played a major role in determining whether particular hardware items met this article's definition of a PC-based DSO. Quite a few vendors take strenuous exception to the requirement that to qualify

PC-based DSOs can offer *very high performance. Typical of high-speed waveform digitizers that you can use with a PC is the Model 500 from Nicolet.*



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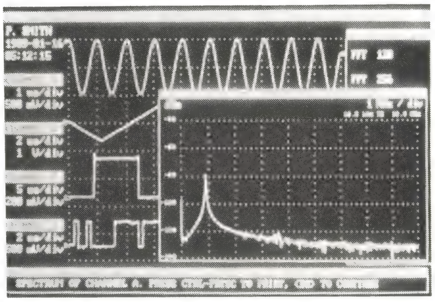
CIRCLE NO 79

as a DSO a unit should be able to display 5-MHz analog signals.

Many products that are called PC-based scopes by their vendors digitize at a maximum rate of 1M samples/sec or less. These slower units have been well accepted in certain areas—for example, in biomedical engineering and in work involving transducers and electromechanical systems. Indeed, compared with faster products, vendors have thus far delivered many more of these low-frequency PC-based scopes. Nonetheless, the 5-MHz criterion came from a desire to include only products that an EE doing electronic design work would be likely to consider for general-purpose use.

Due to both application differences and design constraints, the designers of units that acquire



Software supplied with PC-based scopes *adds important capabilities. Here, Gage's software allows the simultaneous viewing of a signal in the time domain and its frequency-domain spectrum derived by using FFTs.*

wideband signals primarily for display have somewhat different priorities than do the designers of lower-frequency data-acquisition hardware (**Ref 4**). For example, for waveform display, a resolution of eight bits is usually adequate. For process control, on the other hand, much higher resolution is often needed.

Although eight bits of vertical resolution might be all you need in a DSO, you shouldn't assume that because a unit's A/D converter has an 8-bit output that the DSO can actually resolve eight bits. Noise and nonlinearities arising from various sources within the scope can make the unit's *effective resolution* lower than the ADC's word length. Some manufacturers publish effective resolution specs; others leave it to you to determine the parameter's value.

Actually, published specs on effective resolution can sometimes prove misleading. The parameter usually depends on the "aperture uncertainty" of the sample-and-hold (S/H) amplifier that precedes the

For more information . . .

For more information on the PC-based oscilloscopes and software discussed in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

Asyst Software Technologies Inc
100 Corporate Woods
Rochester, NY 14623
(800) 348-0033;
in NY, (716) 272-0070
FAX 716-272-0073
Circle No 705

BitWise Designs Inc
297 River St
Suite 501
Troy, NY 12180
(800) 367-5906;
in NY, (518) 274-0755
TLX 710-110-1708
Circle No 706

Gage Applied Sciences Inc
5905 Chemin St François
Montreal Quebec, Canada H4S 1B6
(514) 337-6893
FAX 514-337-8411
Circle No 707

Golem Systems Inc
3533 Old Conejo Rd
Suite 124
Newberry Park, CA 91320
(800) 942-1441;
in CA, (805) 498-6444
Circle No 708

Heath/Zenith Instruments
Hilltop Rd
St Joseph, MI 49085
(616) 982-3200
TLX 275411
Circle No 709

Kontron Electronics
630 Clyde Ave
Mountain View, CA 94039
(415) 965-7020
TWX 910-378-5207
Circle No 710

LeCroy Corp
700 Chestnut Ridge Rd
Chestnut Ridge, NY 10977
(800) 553-2769;
in NY, (914) 578-6038
TLX 710-577-2832
Circle No 711

Metrabyte Corp
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Taunton, MA 02780
(508) 880-3000
TLX 503989
Circle No 712

National Instruments Corp
12109 Technology Blvd
Austin, TX 78727
(800) 531-4742;
in TX, (800) 433-3488
TLX 756737
Circle No 713

Nicolet Instrument Corp
5225 Verona Rd
Madison, WI 53711
(800) 356-3090;
in WI, (608) 273-5008
FAX 608-273-5061
Circle No 714

Orion Instruments Inc
702 Marshall St
Redwood City, CA 94063
(415) 361-8883
TLX 530942
Circle No 715

Rapid Systems Inc
433 N 34th St
Seattle, WA 98103
(206) 547-8311
TLX 265017
Circle No 716

Signal Technology Inc
5951 Encina Rd
Goleta, CA 93117
(800) 235-5787;
in CA, (805) 683-3771
TWX 910-334-3471
Circle No 717

Sonotek Inc
8700 Morrissette Dr
Springfield, VA 22152
(703) 440-0222
TLX 910-250-5257
Circle No 718

Virtual Instruments Co
23 FJ Clarke Circle, No. 5
Bethel CT, 06801
(203) 748-2000
FAX 203-798-8863
Circle No 719

ADC; that is, the uncertainty in determining the exact instant at which the S/H amplifier captures the input signal. Aperture uncertainty can depend on the acquired signal's slew rate. As a result, a unit's effective resolution can depend on the characteristics of your signal.

When a product using the IBM PC or PC/AT bus acquires more than approximately 250k to 300k samples/sec (the exact value depends on the clock speed the PC uses when accessing the I/O bus), it must include onboard memory; the bus simply can't absorb data any faster. If you're acquiring waveform data, the limitations on memory depth imposed by the amount of high-speed RAM the product's designers can fit on a pc board (and the amount that users will be willing to pay for) are not severe. After all, if eight bits of vertical resolution—equivalent to one part in 256—are adequate, then for many purposes you can get by with the same amount of horizontal resolution.

However, there are other situations in which deeper memory is a real advantage. A deep memory allows a product to maintain high sampling rates even when the effective sweep speed is low. And as already pointed out, you need high sampling rates to reproduce many waveforms with adequate fidelity. Deep memory is an area where PC-based DSOs shine—many of the products listed in **Table 1** offer deeper memory than is common in instrument-level scopes.

On units with shallow memory, you may only be able to use the advertised maximum sampling rate at the fastest sweep speeds. Therefore, you may only be able to view a brief portion of the signal without lowering the sampling rate to a point where aliasing becomes a problem. For example, if a unit has a 512-word memory and acquires 10M samples/sec, it will fill the memory in 51.2 μsec. If you want to view a waveform whose duration is longer than 51.2 μsec, you'll need to lower the sampling rate. On the other hand, at 10M samples/sec, a board with a 128k-word waveform memory can acquire a waveform whose duration is over 13 msec. Usually, when a DSO can acquire such long samples, the software will let you "zoom in" to obtain a detailed view of specific portions of the waveform.

As product areas within electronics go, the instrumentation field is relatively conservative. Consequently, the majority of instrument users take a "show me" attitude toward new developments. For PC-based-instrument vendors, this attitude has certainly filled the road to success with more obstacles than they would have liked to find. PC-based scopes are, relatively speaking, still in their infancy. Nonetheless, if the enthusiasm these products have engendered so far is any indication, you'll be hearing a lot more about them in the next few years. Nonetheless, if you're considering a DSO purchase now, you'd be well advised to carefully consider whether a PC-based scope is right for you. EDN

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3. Steer, R W, "Antialiasing filters reduce errors in A/D converters," *EDN*, March 16, 1989, pg 171.
4. Travis, B, "PC-resident analog-I/O cards," *EDN*, September 15, 1988, pg 150.

Article Interest Quotient
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High 512 Medium 513 Low 514

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CIRCLE NO 85

TABLE 1—REPRESENTATIVE PC-BASED OSCILLOSCOPES, PC-BASED HIGH-SPEED WAVEFORM DIGITIZERS, AND COMPATIBLE SOFTWARE

VENDOR	MODEL	US BASE LIST PRICE	HARDWARE CHARACTERISTICS: CONFIGURATION	CHANNELS	BANDWIDTH (MHz)	MAX SAMPLING RATE (M SAMPLES/SEC): REAL-TIME	MAX SAMPLING RATE (M SAMPLES/SEC): EQUIVALENT	TYPE OF EQUIVALENT-TIME SAMPLING	NO. OF BITS	FULL-SCALE INPUT: MIN (mV)	FULL-SCALE INPUT: MAX (V)	SWEEP TIME (FULL SCREEN): MIN	SWEEP TIME (FULL SCREEN): MAX	MAX POINTS WAVEFORM	HARD DISK
ASYST SOFTWARE	ASYST	$2095	SOFTWARE ONLY—NOT APPLICABLE												REQUIRED
BITWISE DESIGNS	LOGIC-20 ANALOG POD	$890	8- OR 13-IN. PC BUS CARD; 2×3×4-IN. UNIT	1 OR 2	20	25	N/A	N/A	7	2500	100	10 µSEC	10 SEC	256; 32k THROUGH SOFTWARE	SUPPORTED
	8100	$4400	FULL-LENGTH IBM PC/AT BUS CARD: USABLE IN PC/XT	2	>50	100	800	SEQUENTIAL	8	31	5	40 nSEC	84 mSEC	64k	AT LEAST 2M BYTE
GAGE APPLIED SCIENCE	COMPU-SCOPE 220	$1995	FULL-LENGTH CARD FITS IBM PC AND PC/AT BUS	2	20	40	N/A	N/A	8	100	10	100 nSEC	10 SEC	256k	SUPPORTED
GOLEM SYSTEMS	GOLEM-20	$1400	FITS IBM PC AND PC/AT BUSES	2	20	40 (20 USING 2 CHANNELS)	NONE	N/A	8	2000	200	25 NSEC	5 SEC	4k; 16k AND 128k OPTIONAL	SUPPORTED
HEATH/ZENITH	SDS-5000	$1995	TWO PC BUS CARDS	2	50	20 (BOTH CHANNELS)	5000	SEQUENTIAL	8	40	40	100 nSEC	6.4M SEC	4k, 16k OPTIONAL	RECOM-MENDED
KONTRON	W+W 700	$13,000	17.5×8.75×20.5 IN.	1 TO 32	25	50	50 WITH 12-BIT PLUG IN	SEQUENTIAL	8 TO 12	100	100	NOT SPECI-FIED	NOT SPECI-FIED	256k (1M Q4 '89)	OPTIONAL
LECROY	6880B	$20,990	BENCHTOP UNIT 14×11.5×18.7-IN. RACK UNIT 15.6×19×21.7-IN. IEEE-488 CARD	1 TO 84	500	1348	NONE	N/A	11	50	50	8 nSEC	7.4 µSEC	10k	SUPPORTED
METRABYTE	PCIP-SCOPE	$999	FULL-LENGTH IBM PC BUS CARD	2	10	20	500	SEQUENTIAL	8	20	20	2 µSEC	5 SEC	2k WITH 1 CHANNEL	
NATIONAL INSTRUMENTS	MEASURE	$495	SOFTWARE ONLY—NOT APPLICABLE												SUPPORTED
	LAB-WINDOWS	$495 ($895 FOR ADVANCED ANALYSIS LIBRARY)	SOFTWARE ONLY—NOT APPLICABLE												2M BYTES REQUIRED
	LABVIEW	$1995	SOFTWARE ONLY—NOT APPLICABLE												5M BYTES REQUIRED
NICOLET	4094 AND 4180 SOFT-WARE	$12,900	EXTERNAL UNIT 9.9×16.9×18.7 IN., IEEE-488 CARD	2 OR 4	100	200	3200	SEQUENTIAL INTERPOLATED	8	100	40	312.5 nSEC	20,000 SEC	16k	SUPPORTED
ORION	OMNILAB 9420	$8900	15×5.4×11.5 IN. PLUS CARD FOR IBM PC, PC/AT, OR MICROCHANNEL	2 ANALOG	100	204	680	RANDOM	8	80	160	2 nSEC/DIV	1 SEC/DIV	96k	10M BYTE RECOM-MENDED
RAPID SYSTEMS	R2000M	$3295	5-IN. IBM PC OR PC/AT BUS CARD PLUS BOX 3×14×15-IN.	2	10	20	NONE	N/A	8	256	512	12.5 µSEC	250 SEC	128k	NOT REQUIRED
	R370	$4495	13-IN. IBM PC OR PC/AT BUS CARD PLUS BOX 3×14×15-IN.	2	10	20	NONE	N/A	8	256	512	12.5 µSEC	250 SEC	64k	NOT REQUIRED
SIGNAL TECHNOLOGY	ILS-PC V6.1	$1875	SOFTWARE ONLY—NOT APPLICABLE												7M BYTES MIN
SONOTEK	STR*8100	$4400	FULL-LENGTH IBM PC/AT BUS CARD USABLE IN XT	2	>50	100	800	SEQUENTIAL	8	31	5	40 nSEC	84 mSEC	64k	SUPPORTED
	STR*825	$1750	FULL-LENGTH IBM PC BUS CARD NO SKIRT	1 OR 2	35	25	200	SEQUENTIAL	8	1000	10	40 nSEC	172 nSEC	64k	SUPPORTED
	DIGI-SCOPE	$750	SOFTWARE ONLY—NOT APPLICABLE												RECOM-MENDED
VIRTUAL INSTRUMENTS	533	$1995	FULL-LENGTH IBM PC BUS CARD	2	10	25	NONE	N/A	8	40	40	1.25 µSEC	250 SEC	8k	SUPPORTED

NOTES:
1. UNLESS OTHERWISE NOTED UNDER COMMENTS, ALL UNITS OFFER SINGLE-ENDED INPUTS.
2. VIDEO DISPLAY MODES: CGA—COLOR GRAPHICS ADAPTER; EGA—ENHANCED GRAPHICS ADAPTER; VGA—VIDEO GRAPHICS ARRAY; HERCULES—HERCULES GRAPHICS CONTROLLER
3. PRINTER DRIVERS: GSS—GRAPHICS SOFTWARE SYSTEM; HPGL—HEWLETT-PACKARD GRAPHICS LANGUAGE; NEC—NIPPON ELECTRIC CORP
4. FILE FORMATS: ASYST AND DADISP REFER TO THE FILE FORMATS THAT ORIGINATED WITH THE CORRESPONDINGLY NAMED SOFTWARE PACKAGES. LOTUS, WKS, AND 1-2-3 REFER TO FORMATS ORIGINALLY DEVISED BY LOTUS DEVELOPMENT CORP FOR THE PROGRAM 1-2-3. DIF—DATA-INTERCHANGE FORMAT.

SOFTWARE CHARACTERISTICS																	
VIDEO DISPLAY MODES[2]					PRINTER DRIVERS[3]	COMPATIBLE WITH MANY VENDORS' HARDWARE?	SUPPORTS STANDARD FILE FORMATS[4]	MATHEMATICAL OPERATIONS PERFORMED								COMMENTS
CGA	HERCULES	EGA	VGA	MACINTOSH				+	−	×	AVE.	∫	d/dt	FILTER	FFT	
✓	✓	✓	✓		HPGL SIZE A, B; IBM GRAPHICS; LASER JET	ACCEPTS DATA FROM IEEE-488 BOARDS	DIF, WKS BINARY, ASCII, ASYSTANT	✓	✓	✓	✓	✓	✓	✓	✓	AUTOMATIC AND CUSTOM GRAPHICS, PROGRAMMABILITY, OPTIONAL RS-232C, A/D AND D/A INTERFACING.
✓	✓	✓	✓		USES IBM PRINTSCRN UTILITY	BITWISE ONLY	ASCII				✓					SIMULTANEOUS ANALOG AND LOGIC-ANALYZER DISPLAYS.
ANY SUPPORTED BY MICROSOFT WINDOWS					MANY INCLUDING POSTSCRIPT	BITWISE (LAS) AND SONOTEK	NOT SPECIFIED	✓	✓	✓	✓	✓	✓		✓	
	✓	✓	✓		EPSON AND COMPATIBLES	GAGE ONLY	LOTUS DADISP ASYST	✓	✓	✓	✓	✓	✓	WINDOWING	✓	INCLUDES FREQUENCY COUNTER. WAVEFORM MEMORY MAPPED TO PC MEMORY—NO NEED FOR DMA.
✓	✓	✓	✓				LOTUS DADISP ASYST ASCII	✓	✓		✓	✓	✓		✓	ALSO PERFORMS INVERSE FFT, WEIGHTED SUMS, WAVEFORM STATISTICS, CURSOR-CONTROLLED MEASUREMENTS.
✓		✓			1 FOR IBM AND EPSON	ONLY HEATH/ZENITH	ASCII BINARY DADISP	✓	✓		✓					CAN DISPLAY EIGHT WAVEFORMS AT ONCE. ROLL MODE FOR SLOW SIGNALS. YOU CAN SET ALARM BANDS AND LOG ALARMS.
PROPRIETARY MONOCHROME DISPLAY ADAPTER					EPSON, HPGL	KONTRON ONLY	LOTUS ASYST DADISP	✓	✓	✓	✓	✓	✓	✓	✓	MAINFRAMES ACCOMMODATE MODULAR SAMPLING UNITS. MAINFRAME CONTAINING 80286-BASED PC IS AVAILABLE.
✓	✓	✓	✓		>40 DOT-MATRIX AND LASER PRINTERS, PLOTTERS	ANY CAMAC[5]	DIF, WKS ASCII, PACKED BINARY, BASIC	✓	✓	✓	✓	✓	✓	✓	✓	SOFTWARE ALSO PERFORMS ARRAY PROCESSING AND CURVE FITTING. THIS MODEL IS ONLY ONE OF A BROAD LINE OF HIGH-PERFORMANCE DIGITIZERS, ANY OF WHICH CAN BE CONTROLLED BY A PC.
✓		6				METRABYTE	ASCII[1]									SOFTWARE CONSISTS OF DRIVERS USABLE WITH HIGH-LEVEL LANGUAGES.
✓	✓	✓	✓		HPGL, DOT-MATRIX, LASER	IEEE-488, RS-232C-COMPATIBLE	DIF, WKS PIC	✓ VIA SYMPHONY, 1-2-3	✓	✓	✓					INSTRUMENT DRIVERS AVAILABLE AT NO COST FOR OVER 30 HEWLETT-PACKARD PRODUCTS INCLUDING DSOs.
✓	✓	✓	✓		HPGL, DOT-MATRIX	SAME AS MEASURE	ASCII	✓	✓	✓	✓	✓	✓		✓	HIGH-LEVEL INSTRUMENT LIBRARY SIMPLIFIES PROGRAMMING OF MANY INSTRUMENTS.
				COLOR AND MONOCHROME	PLOTTER, LASER	NATIONAL INSTRUMENTS	WKS, ASCII BINARY	✓	✓	✓	✓	✓	✓	✓	✓	MACINTOSH-BASED, MOUSE-DRIVEN SOFTWARE WITH PULL-DOWN MENUS AND WINDOWS.
✓		✓			HPGL, DOT-MATRIX	NICOLET ONLY	PROPRIETARY	✓	✓	✓	✓	✓	✓	✓	✓	SOFTWARE PERFORMS MANY FUNCTIONS NOT LISTED AT LEFT. WORKS WITH SEVERAL TERMINATE-AND-STAY RESIDENT UTILITIES. VENDOR OFFERS OTHER DIGITIZERS AS WELL.
	✓	✓	✓		DOT-MATRIX	ORION ONLY	LOTUS ASCII DADISP	✓	✓	✓	✓	✓	✓			ALSO INCLUDES LOGIC ANALYZER, PATTERN GENERATOR, ARBITRARY-WAVEFORM GENERATOR, FREQUENCY COUNTER, AND RLC METER.
✓		✓			DOT-MATRIX, LASER	RAPID SYSTEMS ONLY	123, ILS ASYST, DADISP, dBASEIII MATHCAD	✓	✓						✓	ANALOG FRONT END IS FULLY PROGRAMMABLE. INPUTS ARE FLOATING. YOU CAN SELECT A 50Ω INPUT IMPEDANCE. SOFTWARE CAN AUTOMATICALLY SAVE WAVEFORMS TO DISK. REAL-TIME FFT SOFTWARE IS OPTIONAL.
✓		✓			DOT-MATRIX, LASER	RAPID SYSTEMS ONLY	SAME AS R2000M	✓	✓		OF SPECTRA				✓	UNIT INCORPORATES TM32010-BASED DSP THAT CALCULATES 10 1k-POINT FFTs/SEC. PC UPDATES FFT DISPLAY SEVEN TIMES/SEC.
✓	✓	✓	✓		GSS-SUPPORTED DRIVERS, HPGL, PLOT 10	METRABYTE, IBM DACA, ANALOG DEVICES	PROPRIETARY	✓	✓	✓	✓	✓	✓	✓ OCTAVE BAND	✓	REQUIRES 8087, 80287 OR 80387 COPROCESSOR. PERFORMS PATTERN RECOGNITION AND DATA COMPRESSION. EXPLICITLY SUPPORTS LISTED VENDORS' HIGH-RESOLUTION, LOWER-SPEED DATA-ACQUISITION BOARDS.
✓		✓	✓		EPSON, NEC	SONOTEK ONLY					✓					SOURCE CODE PROVIDED FOR DRIVERS CALLABLE FROM "C". HARDWARE SUPPORTS PRE- AND POST-TRIGGERING AND MULTIPLE BOARDS.
✓		✓	✓		EPSON, NEC	SONOTEK ONLY					✓					MODEL STR*832 ($2100) IS SIMILAR BUT SAMPLES 28% FASTER.
✓		✓			EPSON, NEC	SONOTEK ONLY	PROPRIETARY				✓				✓	AS SCOPE, UPDATES 20 TO 30 TIMES/SEC; AS SPECTRUM ANALYZER, UPDATES EACH SEC.
	✓				DOT-MATRIX	VIRTUAL INSTRUMENTS	ASCII				✓	✓				SOFTWARE CALCULATES PEAK, P-P, MEAN, RMS (AC+DC), AND AC RMS VOLTAGE, TIME, PULSE DURATION, FREQUENCY, AND DUTY CYCLE.

5. CAMAC—A MODULAR INSTRUMENTATION STANDARD THAT ORIGINATED IN NUCLEAR RESEARCH AND IS NOW MORE WIDELY USED.
6. EXPECTED AVAILABILITY: 3RD QUARTER 1989.
7. N/A=NOT APPLICABLE.

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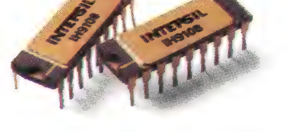

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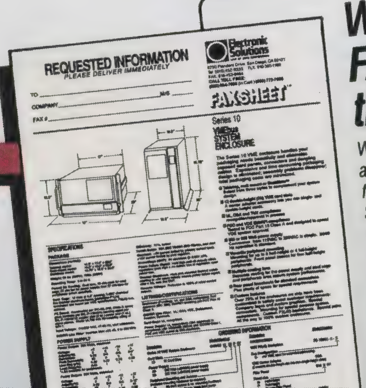
Multibus II	Tabletop 6,7,12,20 slots 7" Rack 7 slots 14" Rack 12,20 slots



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CIRCLE NO 86

80486 32-bit CPU breaks new ground in chip density and operating performance

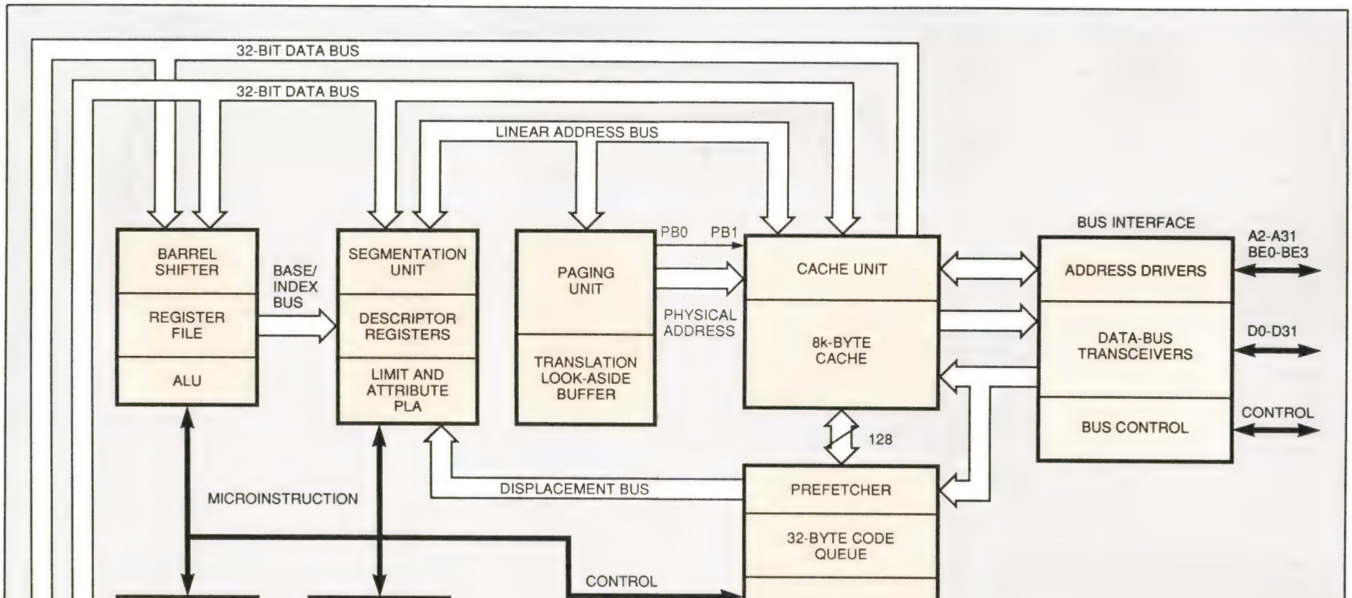
The recently introduced 80486 CPU from Intel not only brings new levels of performance to the personal-computer and workstation market, but also breaks the million-transistor barrier as well. Fabricated in the company's one-micron CHMOS-IV process, the 32-bit 80486 contains 1,180,235 transistors on a 649×414-mil chip. By contrast, Intel's popular 32-bit 80386 chip contains about 275,000 transistors.

The transistor density, per se, is not what's important, however. It's the way the 80486 uses the transistors that brings state-of-the-art performance to this latest example of the company's long line of processors. In addition to an enhanced 386-type CPU, the 80486 contains an enhanced 387-type floating-point unit, an 8k-byte cache, and memory management with paging.

Both the data bus and the address bus of the 80486 are 32 bits wide. In the burst mode, the 80486 can transfer data at a rate of 106M bytes/sec at 33 MHz. The chip has a physical-memory address range of 4G bytes and a virtual-memory address range of 64T bytes.

Although the 486 is a CISC (complex instruction set computer) processor and is 100% binary compatible with the 386, it uses RISC design techniques to achieve a two- to four-fold improvement in performance over the 386 processor. At 25 MHz, the 486 operates at 15 to 20 VAX MIPS and executes 37,000 Dhrystones/sec. Moreover, the on-chip 387 coprocessor provides the 486 CPU with a capability of 6.1M double-precision Whetstones/sec.

The on-chip 387 coprocessor meets the increasing demand for floating-point performance in numeric-intensive applications such as graphics-based user interfaces and computer-aided software engineering. Also adding to the performance of the 486 is the built-in, set-associative cache, which optimizes hit rates and processes frequently used instructions in a single clock cycle. Other features of this powerful chip include multiprocessor in-



Fabricated in one-micron CHMOS technology, the 32-bit 80486 CPU *contains over one million transistors. Included on chip are an enhanced 386 μP, an enhanced 387 numeric coprocessor, an 8k-byte set-associative cache, and memory-management and paging functions. At 25 MHz, the 80486 operates at 15 to 20 VAX MIPS and executes 37,000 Dhrystones/sec.*

structions, multilevel cache support, bus-snooping logic, and hardware bus arbitration.

Samples of the 25-MHz-version 80486 will be available in the third quarter of 1989. Production quantities will be available in the fourth quarter along with samples of a 33-MHz version. The 80486 comes in a 168-pin pin-grid-array package and costs $950 (1000) for the 25-MHz version.

Introduced with the 80486 CPU are the 82596 32-bit LAN coprocessor and the 85C508 programmable logic device. The 82596 LAN chip is optimized for file servers and single-user and multiuser workstations and minicomputers that are based on the 386 and 486 μPs. The 82596 transfers data at the full 486/386 bus bandwidth and contains the same bus signals to simplify the interface with the coprocessor and the system bus. The 82596CA for the 486 CPU costs $88, and the 82596DX for the 386 CPU sells for $65 (1000).

The 85C508 PLD provides high-speed, function-specific performance to reduce the interface chip count in systems using the 486 and 33-MHz 386 devices. Optimized for pipelined microprocessor architectures, the PLD is implemented in 1.5-μm CHMOS that uses 80% less power than equivalent bipolar devices. The 85C508 comes in a 28-pin plastic leaded-chip carrier and costs $14 (1000).

Also announced with the product introductions is a complete set of hardware and software development tools to debug and integrate 486 applications. These tools preserve customer investment in 386 CPU applications by providing full upward compatibility. Customers can begin development now with current 386 tools that support the 486 instruction set via macros.

These tools include an assembler, linker/locator, object-to-hex converter, and C and PL/M compilers. A Fortran compiler will be available in June. An in-circuit debugger, which allows users to debug high-speed, cached applications while operating in real time at 486 speed, will be available in October.

Although not discussed here, Intel has also announced two other products for the 80386 and 80486 CPUs. The 82320 is a peripheral chip set that's 100% register-level compatible with IBM's micro-channel architecture. The 82350 chip set provides support for the extended industry-standard architecture (EISA), which is being developed by a consortium of computer manufacturers led by Compaq.

The 80486 will not find immediate application in home computers or small-business computers that don't need its power and can't justify its cost; however, according to the company, this latest incarnation of the original 8086 will set new standards of performance for workstations and minicomputers that run on operating systems such as DOS, OS/2, and Unix V/386.

—Dave Pryce

Intel Corp, 3065 Bowers Ave, Santa Clara, CA 95051. Phone (408) 987-8080. TWX 910-338-0026. TLX 346372.

Circle No 735

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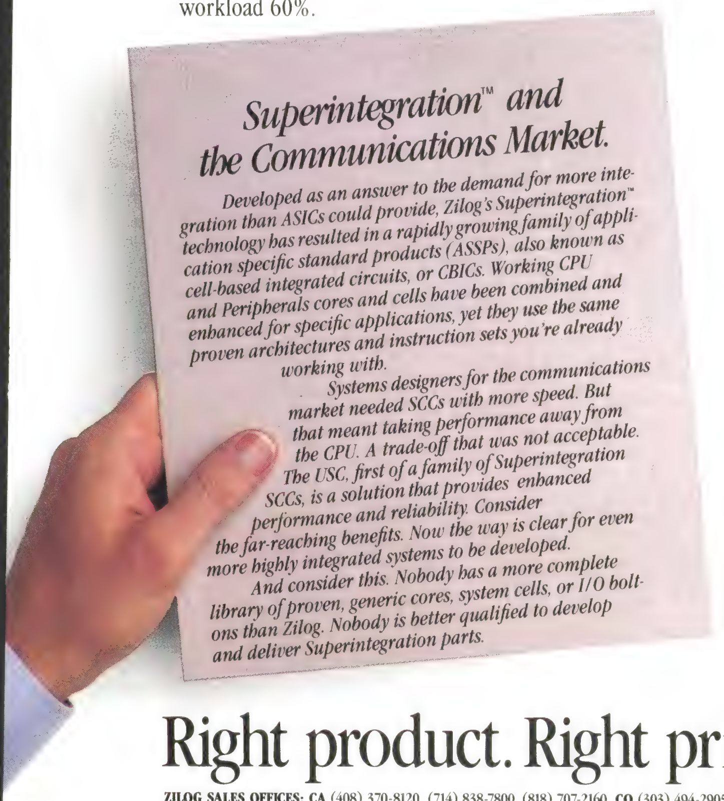

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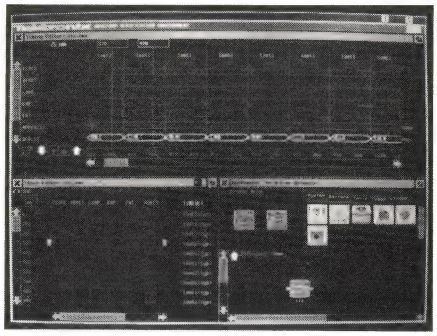
CIRCLE NO 84

Software simplifies linking ASIC design with test

TekWaves graphics-based software from Tektronix simplifies the job of generating test patterns for ASICs. In its initial release, the software runs only on Apollo workstations and supports only the vendor's LV500 ASIC-verification system. However, TekWaves already handles files generated by simulators from six firms. Furthermore, the vendor expects to support additional workstation types. Because the tester-hardware description files are in a format destined to become an industry standard, the vendor expects that the software will be used nearly everywhere that ASICs are designed or tested.

The graphics-based software displays stimulus files in either state or timing formats. You can enter and edit stimuli in both formats. You can, for example, "drag" waveform edges to alter timing and "wire" icons together to create programs without the use of a programming language. All files and file operations appear as icons. You use a mouse and an on-screen representation of a card file to select files and tools. Among the functions you can select in this way are filtering to align timing cycles or to stretch or remove pulses, and checking of stimulus files to ensure that they comply with tester-hardware limitations.

You can import simulation files from Mentor's Quicksim, Daisy's VLAIF, Valid's Sim, HHB's Cadat, Teradyne's Lasar, and GenRad's Hilo. You can export files back to either Quicksim or Hilo. At present, tester-hardware descriptions must be in a not-yet-final version of EDIF (electronic data interchange format), and only the vendor's



***Graphical creation and editing of test patterns** and generation of test programs by "wiring" icons together are just two of the capabilities of TekWaves software that links ASIC design and test.*

LV500 ASIC verification system is described in this format. The vendor is convinced, however, that as soon as the format becomes final, other ATE vendors will use it to describe their testers, and that the format will rapidly become an industry standard.

You can order the initial version of TekWaves for $5000.

—Dan Strassberg

Tektronix Inc, Box 12132, Beaverton, OR 97212. Phone (800) 245-2036.

Circle No 731

Quad-port RAM solves timing and synch problems

Now you can use one multiport serial RAM to loosely couple as many as four computers, thereby solving the contention and arbitration problems that occur when multiple computers try to exchange data. Using 4-way access memory cells, the DS2015 quad-port serial RAM permits simultaneous message passing among four independent devices at transmission rates reaching 4M bps.

This CMOS IC routes data from a given channel to any of the chip's four storage centers, storing the data until the intended recipient is ready for it, distributes the data, then produces a signal when the message transfer is complete. This design provides simultaneous reading of data from any of four independent control points. If one of the multiple computers needs to share a certain area of memory, then that computer can access the memory without regard to what the other computers are doing.

In this way, you avoid having to resort to complex software algorithms and handshaking protocols in order to arbitrate access to memory. Accordingly, you remove an extra processing burden from your μPs by eliminating such overhead logic, which in turn increases the speed with which the μPs can transfer data. You also avoid the data corruption that can occur during bus contention.

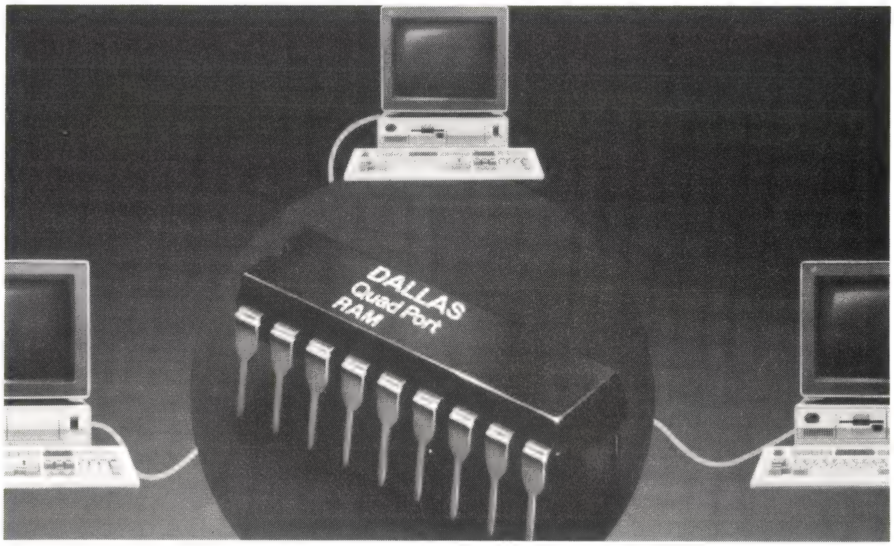
The DS2015 comprises four 8+1-byte storage areas. This chip routes data from a given channel into one of the four storage areas and signals the presence of data in that area. Communication with each of the four ports occurs via a 3-wire serial bus, which is standard in most μPs. Its CMOS fabrication lets you build the DS2015 into a battery-powered, free-standing, 4-port connector.

Available as either an 18-pin DIP or a small-outline package, the DS2015 sells for $6.25 (100).

—***J D Mosley***

Dallas Semiconductor, 4350 Beltwood Parkway S, Dallas, TX 75244. Phone (214) 450-0400. FAX 214-450-0470. TWX 650-244-1669.

Circle No 732



Providing 4-way access to a common memory, *the DS2015 quad-port serial RAM lets you loosely connect as many as four independent computers.*

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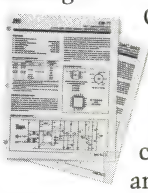

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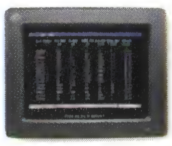

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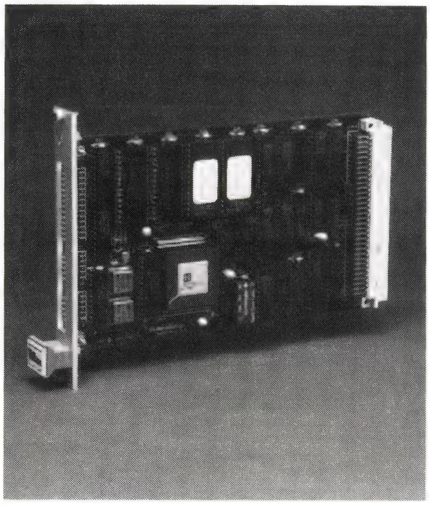
CIRCLE NO 89

Single-height board offers 15-MIPS performance

If your VME Bus application uses the Forth programming language, consider using the V401 as your CPU. The V401 is a single-height 3U board that offers 15-MIPS average performance.

Based on the RTX-2000, a 20-MHz RISC processor from Harris Semiconductor, the V401 has a stack-based architecture and executes Forth as its native language. The board can execute subroutine calls or conditional branches in 100 nsec, has a 400-nsec interrupt latency, and requires 2 μsec for context switch.



Based on the RTX-2000 microcontroller, *the V401 processor board executes Forth programs at 15 MIPS.*

The V401 comes equipped with 64k bytes of CMOS static RAM, three 16-bit counter/timers, a 100-nsec 16×16-bit parallel multiplier, a 16-bit multichannel parallel port, and two RS-232C ports. It handles as much as 64k bytes of EPROM program storage and allows for battery backup of the RAM.

Executing without wait states at an average rate of 15 MIPS, the V401-0 version of the board can produce bursts to 40 MIPS. Running on slower RAM, the V401-1 version of the board has one wait state and offers 7.5 MIPS. The board can transfer data on the VME Bus at 6M bytes/sec; on its parallel port, the board transfers data at 20M bytes/sec concurrent with CPU instruction fetches. You can expand the parallel port with external circuitry to as many as 112 lines.

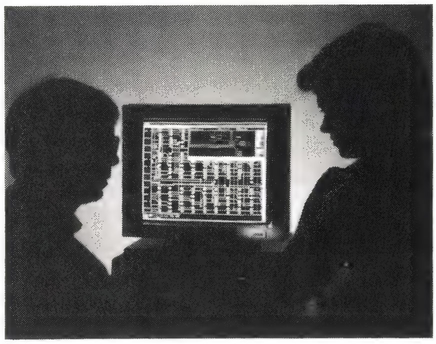
A software development tool kit for the V401 includes a real-time monitor/debugger program on EPROM, an IBM PC-based Forth compiler and editor, file-handling utilities, a disassembler, and an interface cable to connect your IBM PC to the board. The software allows you to interactively monitor and execute code, examine and change memory and registers, and set breakpoints. When you've completed software debug, the tool kit allows you to produce ROM code to replace the monitor/debugger in your final configuration.

The V401-0 costs $1308, and the V401-1 sells for $963 (100). Pricing for the software-development tool kit is $1195. —***Richard A Quinnell***

VMEinc, 542 Valley Way, Milpitas, CA 95035. Phone (408) 946-3833. FAX 408-945-1173. TWX 910-240-9707.

Circle No 736

PC-board tools calculate electrical characteristics



Interactive electrical-parameter checking *lets you change terminator values, alter line widths, and eliminate vias so that your pc-board design can achieve the signal-transmission behavior you want.*

You can interactively analyze your pc-board designs for impedance, propagation delay, capacitance, inductance, and resistance using Allegro release 3.0. This analysis tool helps you evaluate and optimize your pc-board design by performing the appropriate calculations so that you can employ standard design techniques such as eliminating vias, changing etch widths of nets, or modifying the dielectric thickness between layers.

Allegro 3.0 addresses two particular needs of analog designers. First, the software's maximum-component-height design rule check lets you limit component heights for particular areas on the board, automatically flagging components that exceed your height restrictions. Second, the tool supports different analog-design spacing rules, so you can define various net classes and establish different rules for each class.

To improve the testability of your boards, the tool's Design for Accessibility (DFA) Analyzer automatically selects and labels component pin locations (based on your selection criteria) as appropriate points for test-fixture board testing. The DFA Analyzer automatically adds a piece of etch and a test pad to ease surface-mount-device testing.

The Density Iso Bar identifies all the test probes and displays a graphical map that highlights their density. The Iso Bar helps you recognize areas that might overload the bed-of-nails tester so that you can manually move test points to prevent the pc board from moving or tilting on the tester.

After you've completed the design, Allegro 3.0 can optionally perform clean-up functions. You can minimize vias to lower signal resistance and capacitance. The line-smoothing option lets you reduce trace jogs and eliminate 90° angles on traces. By optimizing the trace-line entry into pads, you can decrease the probability of acid entrapment and etch breakouts during wave soldering. The software centers as many as four trace lines between pads, maximizing the space between traces.

Allegro 3.0 costs between \$20,000 and \$50,000, depending on the software configuration, but is supplied free to current Allegro users on maintenance contracts. The software runs on both Sun-3 and Sun-4 workstations and on DEC VAXstations and DECstations.

—Michael C Markowitz

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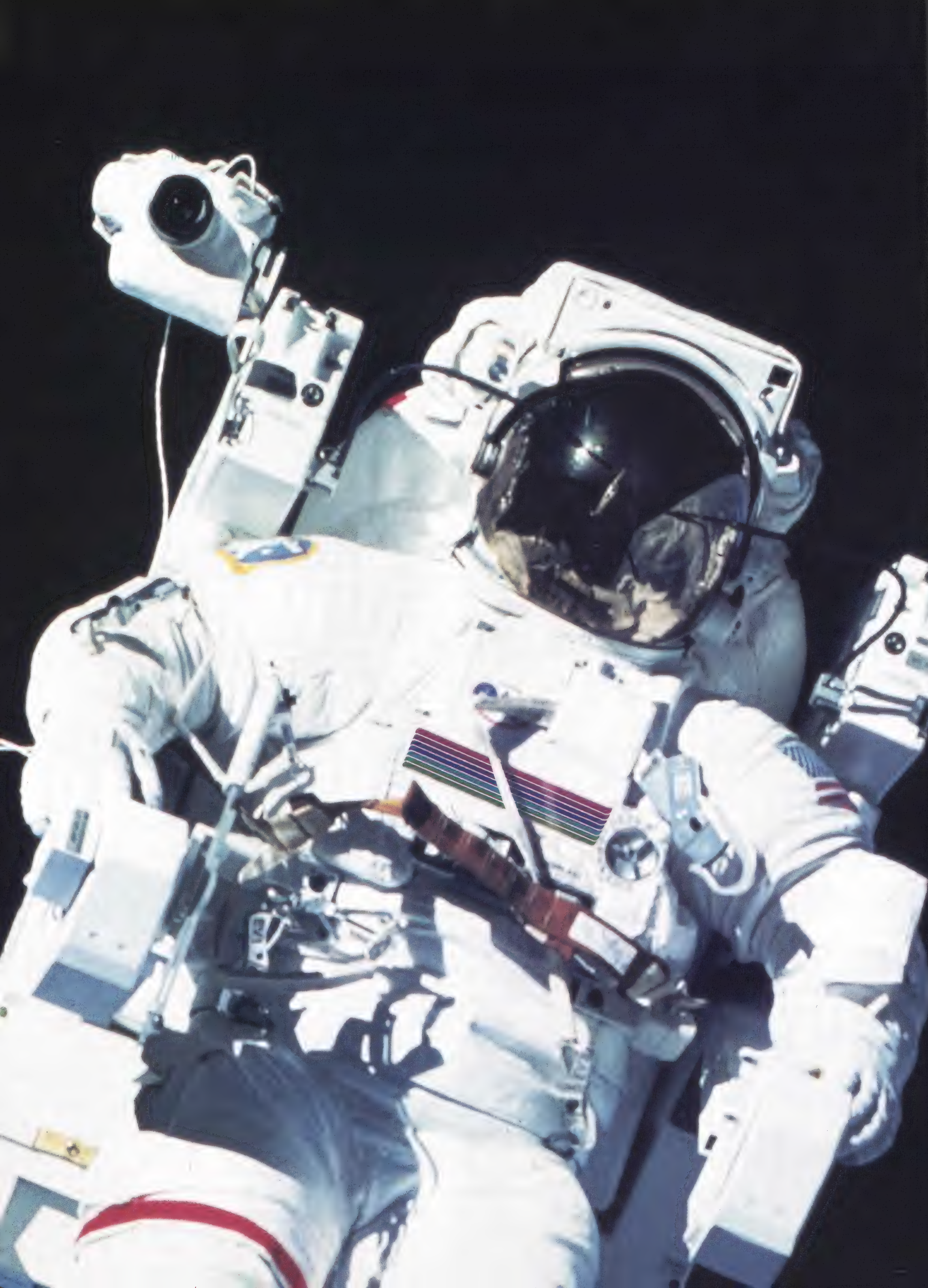

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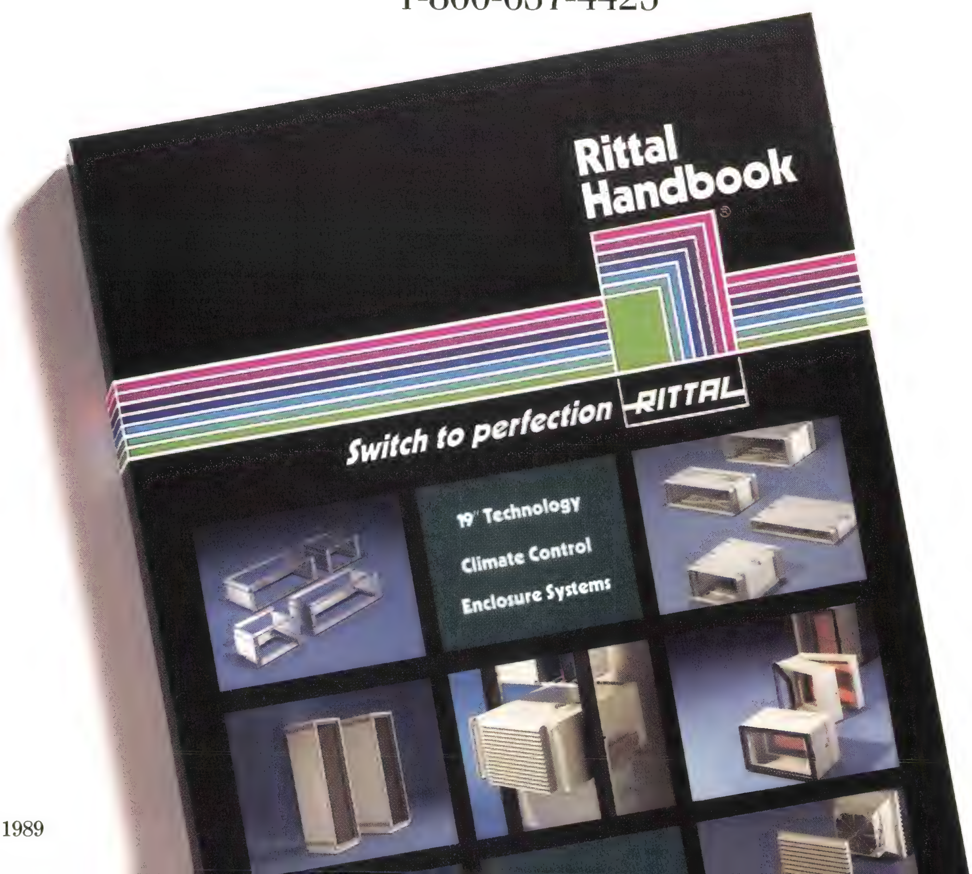

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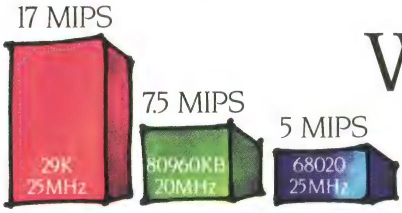

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Today's operational amplifiers are speeding past the op amps of old. Not only are they faster, they're also smaller, cheaper, more efficient, and more diverse. (Photo courtesy Burr-Brown Inc; photography by Brad Hansel, Eglin Photography)

EDN Special Report

Operational amplifiers

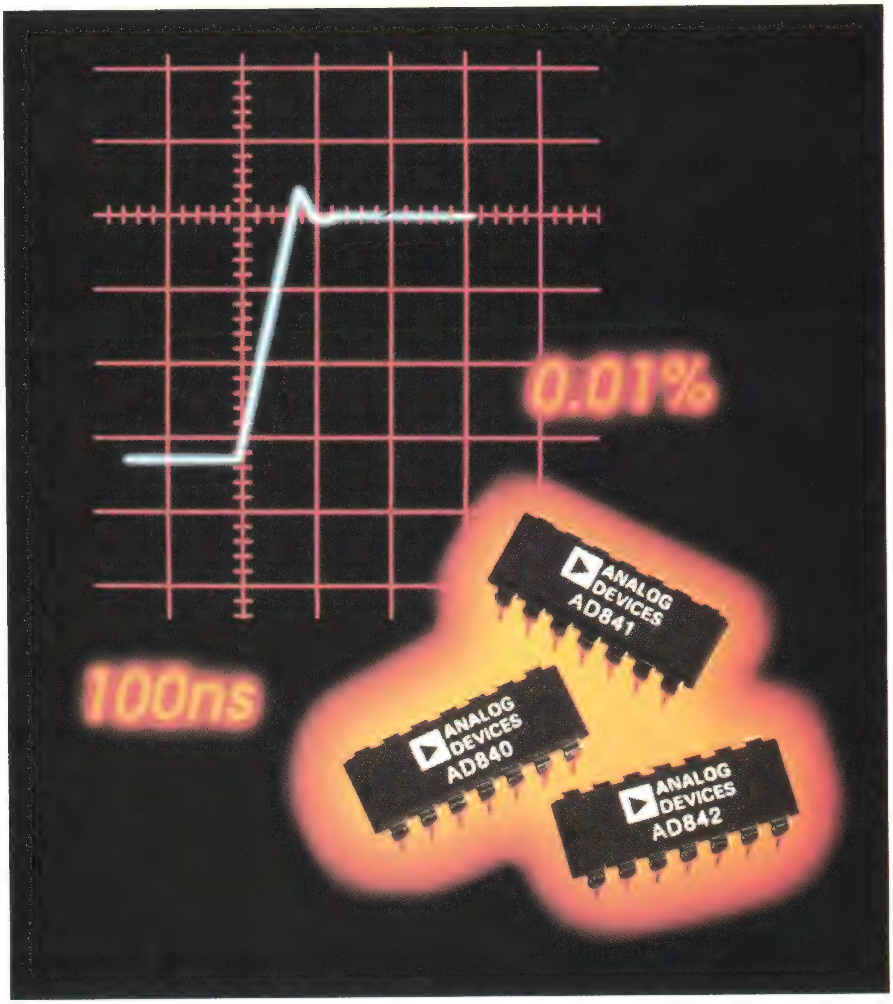
Bill Travis, *Contributing Editor*

The development of operational amplifiers is driven by the need for higher precision, speed, and power efficiency. Many recent products overlap to a significant degree in these application-oriented categories.

Choosing an operational amplifier for your application is steadily becoming less of a give-and-take affair. The traditional tradeoffs, such as that of high speed vs lousy dc performance, are dwindling. Many recently announced op amps combine high speed *and* precision. In a similar vein, the speed performance of low-power op amps is continuously improving. These improvements are coming about through new manufacturing processes as well as innovative circuit architectures.

For example, processing improvements are enabling monolithic devices to encroach on the high-speed territory once held exclusively by hybrid circuits. In fact, some monolithic ICs are displacing many hybrid—as well as home-brew, discrete-component—amplifiers. But in the proud hybrid tradition, you can be sure that hybrid manufacturers will capitalize on the improved monolithics to build even higher-performance hybrids—and the cycle goes on.

Only a couple of years ago, if you needed an extremely high-speed op amp, you would either build it yourself or purchase a relatively expensive hybrid circuit. For example, if your 12-bit A/D- or D/A-conversion application needed a <100-nsec settling time to within a ±0.01% error band, then an appropriate choice would be Teledyne Philbrick's or Datel's $99 1435 hybrid, which typically settles in 70 nsec. For a 150-



A family of high-speed monolithic op amps *from Analog Devices includes bipolar- and JFET-input devices, low-power units, and low-offset amplifiers. The 10-member AD840 Family uses a fully complementary-bipolar process that yields vertical pnp transistors whose speed characteristics approach those of their npn companions.*

nsec settling time to 12-bit accuracy, the \$44 to \$88 1437 hybrid from Teledyne Philbrick or Hycomp would fill the bill.

Now, thanks to such developments as complementary-bipolar processing, which yields fully vertical pnp transistors whose speeds rival those of npn devices, you have a wide choice of stunningly fast monolithic op amps. One example of your range of choices is the AD840 to -849 family of op amps from Analog Devices. The AD840, -841, and -842 devices, which were introduced a little over a year ago, are designed to be stable at gains of 10, 1, and 2, respectively. Typical gain-bandwidth products for the three devices are 400, 40, and 80 MHz, respectively.

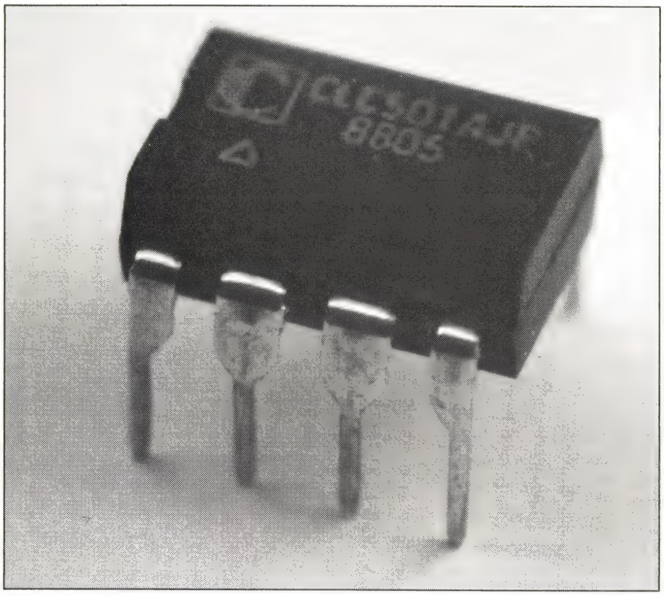
The settling time for the AD841 is 100 nsec typ to ±0.01%; for the other two devices, it is 100 nsec. Other ac parameters include a 200V/μsec min slew rate and a 3.1-MHz min full-power bandwidth with a 500Ω load. You can consider the AD840, -841, and -842 units as a sort of core from which the other AD840 family members depart in specialized ways. For instance, the AD840, -841, and -842 have bipolar inputs that draw 5- to 8-μA max bias currents. Two high-speed, FET-input devices slash this bias current drastically.

The first of the FET-input units introduced by Analog Devices was the AD845, whose bias current is specified at 1 or 2 nA max, depending on the grade. The speed of the FET-input design doesn't match that of the cited bipolar devices: The AD845's minimum slew rate is 94V/μsec, and its typical settling time to ±0.01% is 310 nsec. A more recent FET-input device, the AD843, cuts these compromises considerably. Its slew rate is 160V/μsec min, and it settles to within ±0.01% in 130 nsec typ. The AD843 also takes less input bias current—160 to 250 pA max—and is less noisy—typically 13 vs 25 nV/Hz$^{1/2}$ at 1 kHz—than the AD845.

A transimpedance, or current-feedback, circuit topology is responsible for the scalding slew rates of two other members of the AD84X family. Model AD846 typically slews at 450V/μsec and settles to within ±0.01% in 110 nsec typ. Its real claim to fame, however, is its 75-to-200-μV offset voltage. These low offset levels were formerly the domain of low-speed, "precision" op amps. The other transimpedance amplifier in the family is the AD844, which slews at 1200V/μsec min, 2000V/μsec typ. Its offset voltage is a respectable 150 to 300 μV max, depending on the grade. The AD844 settles to within ±0.1% (but not ±0.01%) in 100 nsec typ.

The last three op amps in the AD84X family are the AD847, -848, and -849, which focus on lowering power dissipation and are stable at gains of 1, 5, and 24, respectively. The devices are fully specified for both

Processing innovations are steadily chipping away the high-speed edge hybrid circuits have traditionally held over monolithic devices.



A current-feedback circuit architecture *yields a relatively gain-independent frequency response in a series of hybrid op amps from Comlinear Corp. At a gain of +20, the 150-MHz CLC501 slews at 1200V/µsec.*

±5 and ±15V supplies and draw 5.7-mA max supply current. With the higher-voltage supplies, the respective gain-bandwidth products are typically 50, 175, and 725 MHz. Settling time to within ±0.1% is 65 nsec typ. Starting prices for the AD840 family range from $2.95 to $6.95 (100).

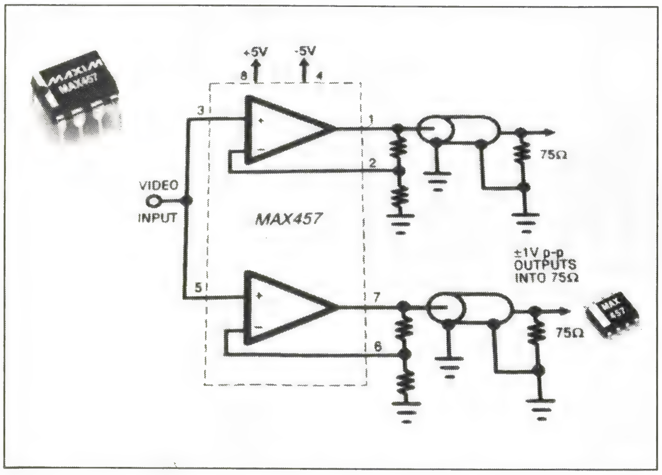
The OP-260 dual current-feedback op amp introduced by Precision Monolithics Inc a little more than a year ago has a typical slew rate of 1000V/µsec at unity gain. It's noteworthy that the device achieves this high speed while drawing only 4.5 mA supply current per amplifier from its ±15V supply. The OP-260 sells for $7.95 (100).

Note that designing an amplifier to settle quickly within a ±0.01% error band is not easy. This error band represents only ±1 mV in a 10V step. Aside from ringing effects and the discharge times of circuit capacitances, a factor that can eliminate an amplifier from contention in the 12-bit-settling marketplace is "thermal tails." If an amplifier is designed without considering the power-induced temperature rises that can occur on a chip, the amplifier's output can exhibit thermal time constants as long as several milliseconds at its output. Careful isothermal design is the key to success.

A new device from Burr-Brown boasts an astonishing ±0.01% settling time of 25-nsec typ. The OPA620 uses a fully complementary bipolar process to achieve a 250V/µsec typ slew rate and a 300-MHz typ unity-gain bandwidth. The amplifier draws a 23-mA supply current from ±5V supplies and costs $9.95 (100). A decompensated version called the OPA621 shaves 5 nsec off the settling time and boosts the slew rate and gain-bandwidth product to 1000V/µsec and 600 MHz, respectively. It sells for $10.15 (100).

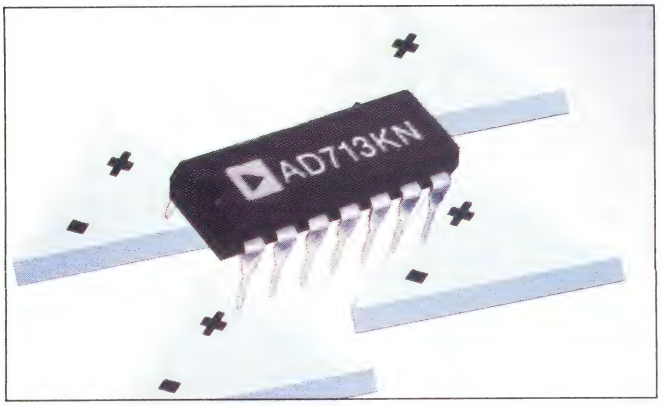
One company that has traditionally used current feedback as a means to achieve fast, gain-independent performance is Comlinear Corp. The company has recently rounded out its series of hybrid amplifiers with a family of monolithic devices that use fully complementary bipolar processing. The CLC400 and -401 spec 15-nsec max settling times to within ±0.05%, or about 2 LSBs at 12 bits. The devices were designed for gains of ±1 to ±8 and ±7 to ±50, respectively. The CLC400's slew rate is 700V/µsec typ at a gain of +2 and 1600V/µsec at a gain of −2. At a gain of +20, the CLC401 has a typical slew rate of 1200V/µsec. Bandwidths for the two devices are typically 200 and 150 MHz, respectively. Prices are $11.55 and $9.25 (100).

A couple of other current-feedback op amps from Comlinear offer both fast settling and a user-settable output-clamping capability. The CLC500, which costs $17.35 (100), is optimized for low-gain (±1 to ±8) applications, such as the input difference amplifier in an A/D converter. The device guarantees a 25-nsec max settling time to within ±0.015%, 15-nsec max to ±0.1%. In fact, although it doesn't show up in the guaranteed specs, the manufacturer claims—and the



CMOS technology addresses video needs *in a series of op amps from Maxim Integrated Products. The ±5V MAX457 drives a 75Ω load, slews at 150V/µsec, and settles to within ±1% in 50 nsec. A related family, the MAX452 through -455, has two, four, or eight multiplexed inputs.*

Dazzling speed performance no longer necessarily entails poor dc performance; recent high-speed monolithic op amps combine high speed and precision amplification.



***This JFET-input quad op amp settles in 1 μsec** to within ±0.015%. Model AD713, the first JFET-input quad from Analog Devices, also has respectable dc specs: a 500-μV max offset voltage and a 200,000V/V min open-loop gain.*

data-sheet artwork corroborates—that the total absence of thermal tails yields a settling characteristic that's much better than the specified ±0.01%, or 12-bit, performance.

An optimized gain of 32 makes Comlinear's $17.10 (100) CLC501 suitable for use as the residue amplifier in subranging A/D circuits. Its settling time—24 nsec max, 12 nsec typ to within ±0.05%, or about 2 LSBs in a 12-bit system—is not quite as clean as that of the CLC500. Most subranging A/D-converter circuits, however, use digital error correction that can compensate for errors of several LSBs during the final conversion cycle.

Aside from fast settling, what sets the CLC500 and -501 apart from other high-speed op amps is their output-clamping facility. In most amplifiers, large overdrive signals at the input drive the output stage into saturation, and the recovery time from saturation can be significant. In the two Comlinear devices, you can apply clamping voltages to designated pins to impart a fast-recovery clamping characteristic to the output. The CLC500, for example, recovers from 2X overdrive in about 10 nsec. The CLC501's recovery time from 32X overdrive is about 1 nsec.

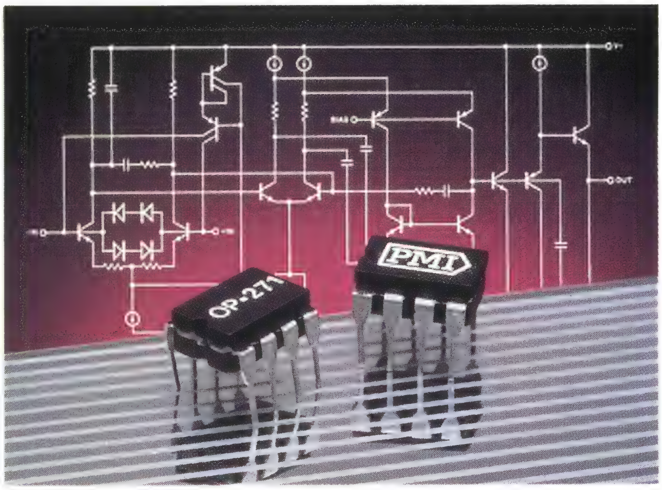
Preliminary data for a new high-speed device from Comlinear points up its suitability for low-power applications, such as battery-powered systems and remote-site installations. You can use a resistor to program the ±5V supply current of the CLC505 from 1 to 9 mA. The operating current, of course, has a direct influence on speed. For example, at 1 mA, the slew rate is 600V/μsec typ, and the ±0.05% settling time is 40 nsec typ. At 9 mA, these figures increase to 1700V/μsec and 12 nsec, respectively. A TBD (to be determined) symbol in the spec column for ±0.02% settling time indicates that the manufacturer plans to characterize the CLC505 for 12-bit settling. A disable capability, which is not explained in detail in the preliminary sheet, conserves power when the amplifier is not in use. The price for the CLC505 is expected to be between $12 and $15 (100).

DI enters the mainstream

When queried about using dielectric isolation (DI) to achieve high op-amp speeds, manufacturers that don't use the process invariably claim that DI parts serve a high-price, out-of-the-mainstream "niche" market. "Sour grapes," says Dean Coleman, VP of marketing at Elantec Inc. Coleman maintains that DI parts need cost no more than comparable-performance, junction-isolated devices. For example, amplifiers that use a fully complementary, junction-isolated process require many more processing steps than do comparable DI-processed units.

Two new DI-processed parts from Elantec underscore Coleman's point. The EL2038, whose price starts at $3.90 (100), slews at 850V/μsec min and settles to within ±0.1% in 100 nsec typ. The part is suitable as a drop-in replacement for Harris's and others' 2539 device—it's 67% faster, dissipates 35% less power, and has a 4X improvement (2 vs 8 mV max) in offset voltage. The EL2038 is stable at gains of 20 and above.

A new unity-gain-stable amplifier from Elantec sells



***Combining a fast settling time and good dc specs,** Precision Monolithics' OP-271 is useful in 12-bit D/A and A/D conversion. It settles to within ±0.01% in 2 μsec and has offset-voltage and open-loop gain limits of 200 μV and 400,000V/V, respectively.*

for $5 (100). The EL2041 has a 90-MHz typ bandwidth, slews at 180V/μsec min, and settles to within ±0.05% in 90 nsec typ. A combination of specs—90-MHz bandwidth, 13-mA supply current, 10,000V/V gain, and ±5 to ±15V supply range—makes the EL2041 a suitable candidate for replacing such devices as Harris's and others' 2541 (40 MHz, 33 mA); Analog Devices' 841 (40 MHz); Burr-Brown's OPA620 (1000V/V, ±5V); and National Semiconductor's LM6161 (50 MHz, 750V/V).

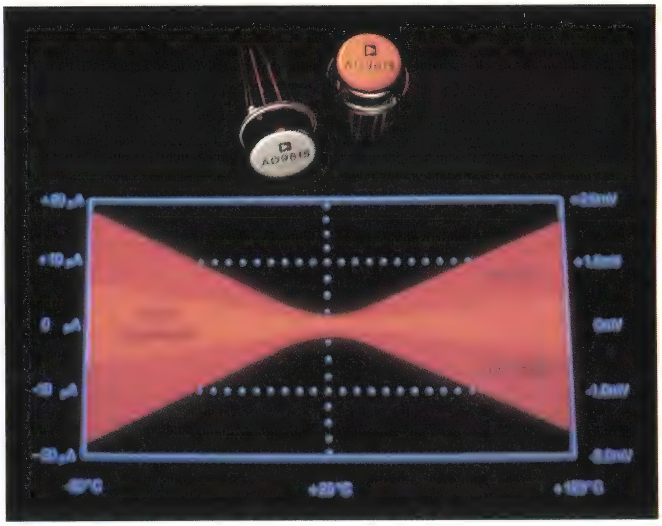
The innovator of the DI process, Harris Corp, has announced several new high-speed op amps. The HFA-0001 and -0005 are suitable for ac-coupled applications, such as video systems and cable driving, that don't require a great deal of dc accuracy. The devices have a 60-mV max offset voltage and a 150V/V open-loop gain. However, they're fast—they slew at 1000 and 600V/μsec typ and settle to within 0.1% in 25 and 20 nsec typ, respectively. Both have built-in 50Ω resistors in their outputs for use as terminating resistors. The HFA-0001 and -0005 draw 65 and 35 mA max from their ±5V supplies and supply 50 and 30 mA to a load, respectively. Prices are $8.05 and $6.39 (100).

Another new Harris op amp suitable for video applications is the HA-2544, which operates from ±15V supplies, slews at 100V/μsec min, and settles to within ±0.1% in 120 nsec typ. Its open-loop gain is 3500V/V min and its price is $3.04 (100).

Speaking of video, a recent device from Harris's RCA division provides ±4V output into 75Ω. The CA3450 operates from ±6V supplies and slews at 160V/μsec when driving a 50Ω load. It settles to within ±0.1% in 35 nsec typ. Its dc specs include a 15-mV max offset voltage and a 1000V/V min open-loop gain. The device sells for $3.75 (100).

Three recent families of devices from Maxim Integrated Products also address video-application requirements. The CMOS-processed MAX457 operates from ±5V supplies and drives 75Ω cables. As usual, dc specs are not paramount in video systems—the amplifier has a 5-mV max offset voltage and open-loop gains that range from 200V/V with a 1-kΩ load to 25V/V with a 75Ω load. The MAX457 slews at 150V/μsec min, settles to within ±1% in 50 nsec typ, and costs $4.45 (1000).

A second CMOS-device family from Maxim provides either a single input or two, four, or eight multiplexed inputs to its video op amp. The MAX452, -453, -454, and -455 operate from ±5V supplies and have offset, gain, slewing, and settling-time specs similar to those of the MAX457. Both of these Maxim video-amplifier families exhibit noise at 0.5 mV rms max over the frequency band of 0 to 40 MHz. Prices start at $2.67 (1000).



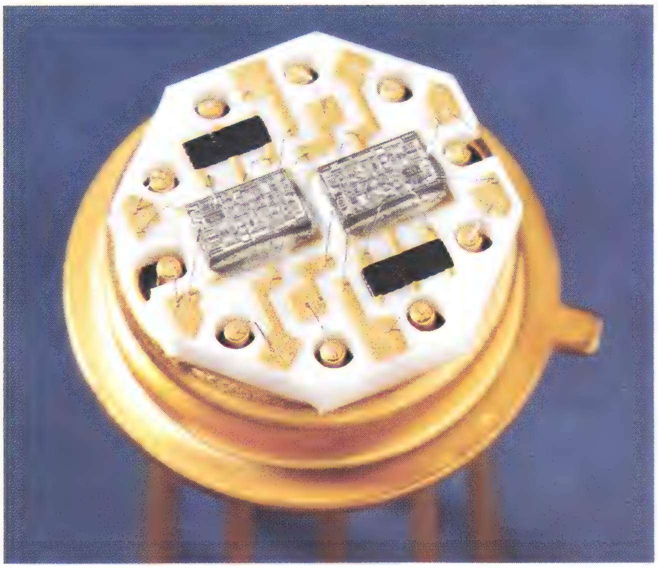
Hybrid circuits represent the technology of choice *in many applications. Operating from ±5V supplies, Model AD9615 from Analog Devices slews at 1400V/μsec and settles to within ±0.1% in 18 nsec.*

The newly released MAX408, -428, and -448 single, dual, and quad op amps from Maxim settle to within ±0.1% in 150 nsec typ and slew at 60V/μsec min. Their ±50-mA output-current capability and their ability to drive capacitive loads make them suitable for many high-speed applications, such as video-cable driving. The amplifier easily handles video-level signals; for instance, it provides a ±2V min output swing into a 51Ω load. Again, dc specs in these applications are not paramount: Operating from ±5V supplies, the MAX408, -428, and -448 feature a 6-mV max offset voltage, a 5000V/V open-loop gain, and 60-dB min each common-mode and power-supply rejection. Prices start at $3.30 (100).

Boasting dc specs—1-mV max offset and 100-dB min open-loop gain—that qualify it as a high-speed, general-purpose amplifier, the HFA-0002 from Harris slews at 100V/μsec min and settles to within ±0.1% in 50 nsec typ. Stable at gains of 10 and above, the device has a gain-bandwidth product of 1 GHz min and costs $7.05 (100). A current-feedback amplifier, the $5.87 (100) HA-5004 is unity-gain stable and slews at 1200V/μsec typ. It settles to within ±0.1% in 50 nsec typ. A useful feature in this device is the presence of TTL inputs that disable the amplifier and provide a high-impedance output on command.

Time was, choosing a high-speed op amp entailed swallowing some terrible dc and noise specs, but

Current feedback is gaining popularity as the architecture of choice in many high-speed applications.



Single and dual hybrid op amps *from National Semiconductor provide high speed and reasonable dc specs. The LH4161 and -4162 single and dual devices slew at 225V/μsec min and settle to within ±0.1% in 120 nsec. Offset-voltage and open-loop-gain limits are 1 mV and 80 dB, respectively.*

emerging fast-settling amplifiers are going a long way toward eliminating this bitter pill. Five recent devices, whose settling time to within ±0.01% ranges from 400 nsec to 2 μsec, illustrates the point. First, consider the LF401 from National Semiconductor, a FET-input op amp that settles in 400 nsec max. Its dc specs include a 200-μV max offset voltage and a 100,000V/V min open-loop gain. Its equivalent input noise is 23 nV/Hz$^{1/2}$ at 1 kHz, or 2.3 μV rms typ over the band 10 Hz to 10 kHz. The LF401 sells for $9.60 (100).

Somewhat slower on the settling-time scale, Burr-Brown's soon-to-be-announced FET-input OPA627 clocks in at 600 nsec max. The OPA627 approaches the status of a precision op amp—its dc specs include a 100-μV max offset voltage and a 200,000V/V min open-loop gain. Its equivalent input noise is 30 nV/Hz$^{1/2}$ at 1 kHz, or 2.5 μV p-p max over the band 0.1 to 10 Hz.

The first quad FET-input op amp from Analog Devices has a 1-μsec typ, 1.2-μsec max, settling time to within ±0.01%. The Model AD713, which costs $3.50 (100), has a 500-μV max offset voltage and a 200,000V/V min open-loop gain. Its equivalent input noise is 45 nV/Hz$^{1/2}$ typ at 10 Hz, or 2 μV p-p typ over the band 0.1 to 10 Hz.

Two other recent devices wrap up the discussion of fast, 12-bit-settling monolithic op amps. First, the bipolar OP-271 from Precision Monolithics Inc settles in 2 μsec typ and boasts a 200-μV max offset voltage and a 400,000V/V min open-loop gain. Its equivalent input noise is a low 7.6 nV/Hz$^{1/2}$ typ at 1 kHz, and its price is $4.50 (100). The dual FET-input OPA2107 from Burr-Brown also has a 2-μsec settling time. Its dc specs include a 500-μV max offset voltage and an 84-dB min open-loop gain. Its equivalent input noise is 12 nV/Hz$^{1/2}$ typ at 1 kHz, or 1.2 μV p-p typ over the band 0.1 to 10 Hz. Prices range from $2.93 to $13.42 (100).

Lastly, a series of medium-to-high-speed monolithic op amps too numerous to list is available from VTC Inc. The series includes units that improve on the speed of such industry standards as the 741, as well as single, dual, and quad devices that have 150- to 250-nsec settling times to ±0.1%. Prices range from $2.31 to $13.71 (100).

Advances in monolithic-IC processing notwithstanding, hybrid circuits still, with few exceptions, offer the highest slew rates available. Consider, for example, the AD9610, -9611, and -9615 family of current-feedback hybrids from Analog Devices, which sell for $49.88 (100). The ±15V AD9610 slews at 3000V/μsec min and settles to within ±0.02% in 30 nsec typ. Intended, of course, for high-frequency operation, it has an equivalent input noise of 1.5 nV/Hz$^{1/2}$ max over the band 5 to 150 MHz. (An alternate source for the AD9610 is Sipex Corp of Billerica, MA.)

The somewhat slower ±5V AD9611, priced at $84 (100), slews at 1900V/μsec typ and settles to within ±0.05% in 16 nsec typ. Its equivalent input noise is 1.4 nV/Hz$^{1/2}$ max over the band 5 to 280 MHz. And finally, the ±5V AD9615 slews at 1400V/μsec typ and settles to within ±0.1% in 18 nsec max. Its equivalent input noise is 2 nV/Hz$^{1/2}$ max over the band 5 to 200 MHz, and it costs $79 (100).

"Breathtakingly fast" is not a hyperbole when used to describe the $105 MSK739 hybrid op amp from MS Kennedy Corp. The device slews at 5500V/μsec typ and settles to within ±0.02% in 30 nsec typ. What's amazing about this ±15V device is its precision dc specs, considering its blinding speed. The MSK739's offset voltage is a mere 25 μV typ, its open-loop gain is 115 dB typ, and its equivalent input noise is 0.5 μV rms typ over the band 0.1 to 10 Hz.

A second hybrid device, which was introduced in the past year by MS Kennedy, also deserves the precision label. The Model MSK738 boasts a 25-μV typ, 75-μV max offset voltage and a 100-dB min open-loop gain. It slews at 3200V/μsec min and settles to within 0.01% in 200 nsec typ. Its equivalent input noise is 3.8 nV/Hz

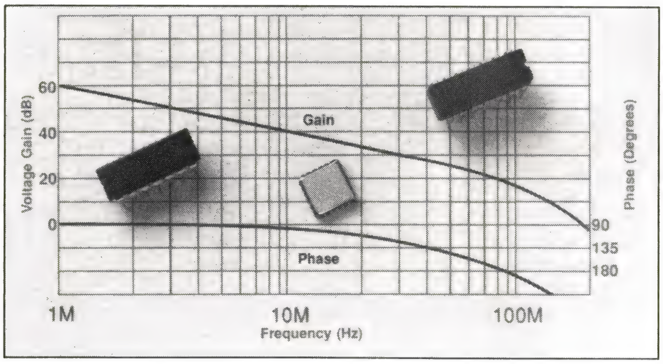
typ at 1 kHz, or 0.15 μV p-p typ over the band 0.1 to 10 Hz. The MSK738 is designed to be used only in the inverting mode and sells for $85 (1 to 24).

To complete your perusal of recent, high-speed hybrid op amps, consider the LH4161 and -4162 single and dual amplifiers from National Semiconductor. These ±15V units slew at 225V/μsec min and settle to within ±0.1% in 120 nsec typ. Their dc specs include a 1-mV max offset voltage and a 10,000V/V min open-loop gain. Their equivalent input noise is 15 nV/Hz$^{1/2}$ at 10 kHz. Like many of the high-speed op amps described earlier, the LH4161 and -4162 devices address video applications by specifying differential-gain and -phase errors of 0.1% and 0.1° typ, respectively. Prices are $3.06 and $6.29 (100).

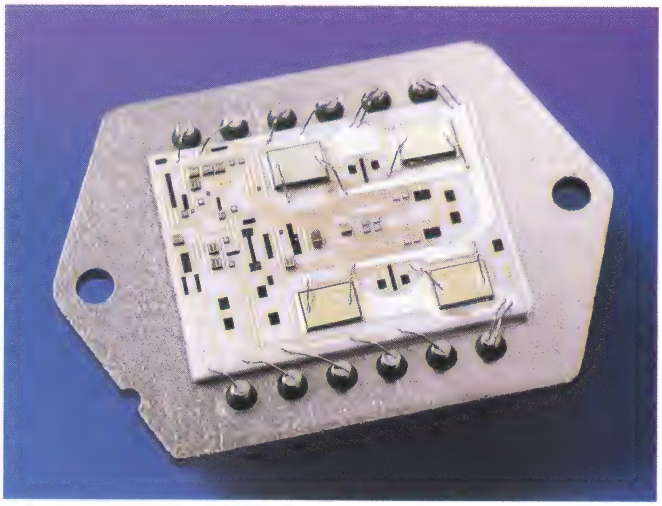
In about a month, Datel will announce two high-speed op amps that settle to 16-bit accuracy. Note that one LSB at 16 bits is 0.0015% of full-scale range. The AM-561 settles to 12-bit accuracy in 155 nsec and to 16-bit accuracy in 260 nsec. The AM-562 settles to 12-bit accuracy in 95 nsec and to 16-bit accuracy in 160 nsec. The devices slew at 300 and 700V/μsec, respectively.

Lower everything

The op amps mentioned so far concentrated on the quest for high speed. In some cases, the high speeds were, happily, accompanied by low offset voltages and relatively low noise. Another class of op amps strives for lowness in everything—offset voltages, input bias currents, noise, supply voltage, power, distortion, and gain errors (low gain errors accrue, of course, from high open-loop gain). The lowest offset voltages available come, naturally, from chopper-stabilized amplifiers, which periodically sample the input and compensate for offset errors.



***Dielectric isolation produces fully vertical pnp transistors** in a series of high-speed op amps from Elantec. The 1-GHz EL2038 is a faster, lower-power 2539 equivalent that slews at 850V/μsec.*



***Hybrid amplifiers provide the highest voltage and current ratings.** Model PA04 from Apex Microtechnology operates from ±100V supplies and supplies a continuous 20A to its load. Capable of dissipating 200W, it uses power MOSFETs in its output stage to eliminate the danger of secondary breakdown. Boost pins increase the available output-voltage swing by about 8V.*

Models MAX430 and -432 from Maxim, which were introduced about a year-and-a-half ago, contain built-in 0.1-μF capacitors to make them drop-in compatible with nonchopper types like the OP-07, OP-77, LM108, and 741. They provide the traditional—for chopper amplifiers—5-μV max offset voltage and 0.05-μV/°C max offset drift and cost $5.65 (100). A couple of recent chopper-amplifier families provide extremely low offset voltages as well as other features.

For example, the TLC2652 from Texas Instruments has a 1-μV max offset voltage at 25°C and a 2.35-μV max offset voltage over temperature (for the highest-grade device). Its open-loop gain is 135 dB min, and its equivalent input noise voltage is 0.8 μV p-p typ from 0 to 1 Hz and 2.8 μV p-p from 0 to 10 Hz. Its 8-pin version is drop-in compatible with the industry-standard 7652. The 14-pin version, however, requires an inversion of clock signals—it uses n-well CMOS devices vs others' p-well transistors. Both versions are priced at $5.35 (100).

A companion to the TLC2652, the Model TLC2654 uses a 10-kHz chopping frequency vs the TLC2652's 450 Hz spec. According to op-amp branch manager Brad Whitney, this high frequency eliminates aliasing problems for input frequencies as high as 5 kHz (the Nyquist frequency). The TLC2654's offset voltage is 10 μV max, 24 μV max over temperature. Its equiva-

Through careful isothermal design, monolithic op amps are eliminating the bugaboo of thermal tails, which excluded many devices from the 12-bit market.

lent input noise is 0.5 μV p-p typ from 0 to 1 Hz and 1.5 μV p-p from 0 to 10 Hz. The device costs $6.31 (100).

A recent chopper amplifier from Linear Technology Corp contains built-in capacitors to provide a 2.5-kHz chopping frequency. The Model LTC1050 has the traditional 5-μV and 0.05-μV/°C max offset and drift specs and provides 130-dB min open-loop gain. The 8-pin version is drop-in compatible with the industry-standard 7650 and 7652 types. According to company president Bob Dobkin, the amplifier contains antialiasing circuitry that eliminates aliasing at frequencies above the 1.25-kHz Nyquist frequency. Its equivalent input noise is 2.1 μV p-p max from 0.1 to 10 Hz, and its price is $2.25 (100).

The chopper amplifiers mentioned so far operate from ±5V supplies. A recent device from Teledyne Semiconductor operates from ±15V and can, therefore, replace bipolar op amps in applications demanding enhanced precision. Models TSC9420 and -9421 have the standard 5-μV max offset voltage and an equivalent input noise of 2.1 μV p-p typ from 0.1 to 10 Hz. The device is pin compatible with Maxim's MAX420 and -421 chopper amplifiers. Both devices are priced at $2.06 (10,000).

On the theme of offset voltage, Raytheon has intro-

Manufacturers of operational amplifiers

For more information on operational amplifiers such as those described in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

Advanced Linear Devices Inc
1180 F Miraloma Way
Sunnyvale, CA 94086
(408) 720-8737
Circle No 650

Analog Devices Inc
Route 1 Industrial Park
Norwood, MA 02062
(617) 329-4700
Circle No 651

Analog Systems
Box 35879
Tucson, AZ 85740
(602) 792-3202
Circle No 652

Apex Microtechnology Corp
5890 N Shannon Rd
Tucson, AZ 85741
(602) 742-8659
Circle No 653

AT&T Technologies
555 Union Blvd
Allentown, PA 18103
(800) 372-2447
Circle No 654

Burr-Brown Corp
Box 11400
Tucson, AZ 85734
(602) 746-1111
Circle No 655

Cherry Semiconductor Corp
2000 South County Trail
East Greenwich, RI 02818
(401) 885-3600
Circle No 656

Comlinear Corp
4800 Wheaton Dr
Fort Collins, CO 80525
(303) 226-0500
Circle No 657

CTS Corp
Microelectronics Div
1201 Cumberland Ave
West Lafayette, IN 47906
(317) 463-2565
Circle No 658

Datel Inc
11 Cabot Blvd
Mansfield, MA 02048
(508) 339-3000
Circle No 659

Devar Inc
706 Bostwick Ave
Bridgeport, CT 06605
(203) 368-6751
Circle No 660

Elantec Inc
1996 Tarob Ct
Milpitas, CA 95035
(408) 945-1323
Circle No 661

Exar Corp
750 Palomar Ave
Sunnyvale, CA 94086
(408) 732-7970
Circle No 662

Fairchild Camera & Instrument Corp
Box 7882
Mountain View, CA 94039
(415) 962-4011
Circle No 663

Harris/GE Intersil
2450 Walsh Ave
Santa Clara, CA 95061
(408) 996-5000
Circle No 664

Harris/GE/RCA Solid State
Route 202
Somerville, NJ 08866
(201) 685-6000
Circle No 665

Harris Semiconductor Corp
Box 883
Melbourne, FL 32901
(407) 724-7000
Circle No 666

Hitachi America Ltd
2210 O'Toole Ave
San Jose, CA 95131
(408) 435-8300
Circle No 667

Hycomp Inc
165 Cedar Hill Rd
Marlborough, MA 01752
(508) 485-6300
Circle No 668

Linear Technology Corp
1630 McCarthy Blvd
Milpitas, CA 95035
(408) 932-1900
Circle No 669

Linear Technology Inc
Box 498
Ontario, Canada L7R3Y3
(416) 632-2996
Circle No 670

Maxim Integrated Products
120 San Gabriel Dr
Sunnyvale, CA 94086
(408) 737-7600
Circle No 671

Micro Linear Corp
2092 Concourse Dr
San Jose, CA 95131
(408) 262-5200
Circle No 672

Micro Power Systems Inc
3151 Jay St
Santa Clara, CA 95054
(408) 727-5350
Circle No 673

duced a bipolar, nonchopper device that has an offset voltage of 15 μV max. Previous state-of-the-offset-art amplifiers like Linear Technology's LT1012 and Precision Monolithics' OP-97 have a 25-μV max offset spec. The Model RC4097, which costs $1.40 (100), is a low-power (18 mW max) op amp that also offers a 120-dB min open-loop gain. Its equivalent input noise is 0.5 μV p-p typ over the band 0.1 to 10 Hz. A new dual op amp from Raytheon, the $2.05 (100) Model RC4277, has a 30-μV max offset, a 5,000,000V/V min open-loop gain, and 0.35-μV p-p typ noise from 0.1 to 10 Hz.

The chopper-stabilized amplifiers discussed so far rely on charges stored on capacitors to null the amplifiers' offset voltages. It's necessary to periodically "refresh" the capacitors—much as with dynamic RAMs—because the amplifiers' leakage currents drain off the charges. A new amplifier from Maxim uses a radically different autozeroing concept to effect its offset-voltage corrections.

In Maxim's MAX425 and -426 (unity-gain stable and uncompensated, respectively), two internal D/A converters supply the offset-correction signals. The first, a 16-bit DAC with 0.1-μV resolution, corrects the offset voltage of the 50-dB input stage. The second DAC, an 8-bit block, calibrates the second 120-dB amplifier stage. The result is an infrequent need to autozero the

Mitel Semiconductor
360 Leggett Dr
Kanata, Ontario
Canada K2K1X5
(613) 592-5630
Circle No 674

Motorola Inc
Bipolar Linear Div
7402 S Price Rd
Tempe, AZ 85282
(602) 897-3951
Circle No 675

MS Kennedy Corp
8170 Thompson Rd
Clay, NY 13041
(315) 699-8023
Circle No 676

National Semiconductor Corp
2900 Semiconductor Ave
Santa Clara, CA 95051
(408) 721-2274
Circle No 677

NEC Electronics Inc
Box 7241
Mountain View, CA 94039
(415) 960-6000
Circle No 678

Optical Electronics Inc
Box 11140
Tucson, AZ 85734
(602) 624-8358
Circle No 679

Precision Monolithics Inc
1500 Space Park Dr
Santa Clara, CA 95050
(408) 727-9222
Circle No 680

Raytheon Co
350 Ellis St
Mountain View, CA 94039
(415) 968-9211
Circle No 681

SGS Semiconductor Corp
1000 E Bell Rd
Phoenix, AZ 85022
(602) 867-6100
Circle No 682

Signetics Corp
811 E Arques Ave
Sunnyvale, CA 94086
(408) 991-2000
Circle No 683

Silicon General Inc
11861 Western Ave
Garden Grove, CA 92641
(714) 898-8121
Circle No 684

Silicon Systems
14351 Myford Rd
Tustin, CA 92680
(714) 731-7110
Circle No 685

Siliconix Inc
2201 Laurelwood Rd
Santa Clara, CA 95054
(408) 988-8000
Circle No 686

Sipex Corp
Data Linear Div
491 Fairview Way
Milpitas, CA 95035
(408) 945-9080
Circle No 687

Sipex Corp
Hybrid Systems Div
22 Linnell Circle
Billerica, MA 01821
(508) 667-8700
Circle No 688

Sony Corp of America
15 Essex Rd
Paramus, NJ 07652
(201) 368-5000
Circle No 689

Sprague Semiconductor
115 Northeast Cutoff
Worcester, MA 01606
(508) 853-5000
Circle No 690

Teledyne Philbrick
Allied Drive at Rte 128
Dedham, MA 02026
(617) 329-1600
Circle No 691

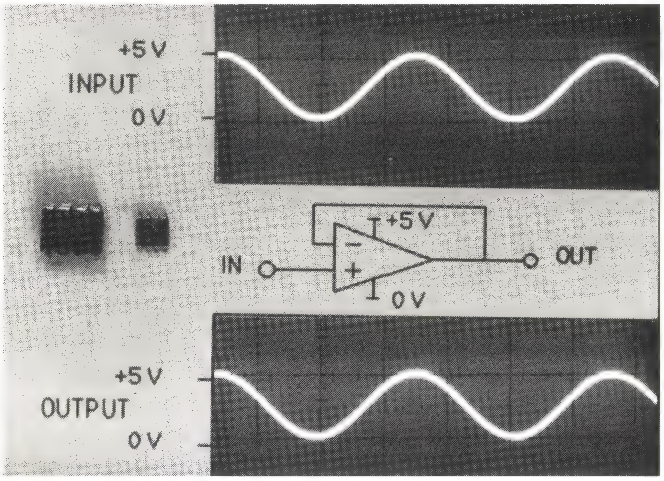
Teledyne Semiconductor
1300 Terra Bella Ave
Mountain View, CA 94039
(415) 968-9241
Circle No 692

Texas Instruments Inc
Semiconductor Group (SC-909)
Box 809066
Dallas, TX 75380
(800) 232-3200, Ext 700
Circle No 693

Toshiba America Inc
2692 Dow Ave
Tustin, CA 92680
(714) 832-6300
Circle No 694

VTC Inc
2401 E 86th St
Bloomington, MN 55420
(612) 851-5000
Circle No 695

The quest for lowness in many crucial specs is responsible for the emergence of op amps having unprecendented low offset voltages, noise, and gain-related errors.



CMOS op amps operate from very low-voltage supplies. *Model ALD1706 from Advanced Linear Devices uses a total power-supply span of 2 to 12V. It's a micropower device that draws 30-pA max bias currents and a 40-μA max power-supply current. This device and several companions are available as standard cells in ALD's ASIC capability.*

amplifier. Logic pins let you choose various modes of autozeroing: manually selected or automatic input autozeroing at 250 Hz (or an external-clock rate); manually selected autozeroing with the input switching disabled; or totally disabled autozeroing.

The validity of the combined analog/digital topology is borne out by the specs. The maximum offset voltage is 1 μV with a drift of 0.02 μV/°C max. The input bias current is 5 pA max, and the open-loop gain is a mind-boggling 180 dB (1 billion) typ, 160 dB (100 million) min. The equivalent input noise is 0.5 μV p-p max over the band 0.1 to 10 Hz. Designed to operate from ±5V supplies, the MAX425 and -426 have unity-gain bandwidths of 0.3 and 8 MHz min and slew at 0.3 and 5V/μsec min, respectively. Both devices sell for $7.50 (100).

A couple of other op amps have recently entered the ≤25-μV offset marketplace. Analog Devices' AD707 and AD708 single and dual bipolar devices have specs of 15-μV max for the single version and 25 μV for the dual. Open-loop-gain specs are 8,000,000 and 5,000,000V/V min, respectively; and the equivalent input noise is 0.35-μV p-p max from 0.1 to 10 Hz. The AD707 and AD708 cost $1.25 and $2.95 (100), respectively. Harris's dielectrically isolated, $4.75 (100) HA-5177 has a 25-μV max offset and a 134-dB min open-loop gain. Its equivalent input noise is 0.6 μV p-p max from 0.1 to 10 Hz.

In terms of noise performance, Linear Technology's $4.95 (100) LT1028 still holds the lowest noise banner. It has a 40-μV max offset voltage, and its noise specs include 1.7 nV/Hz$^{1/2}$ at 10 Hz and 75 nV p-p max over the band 0.1 to 10 Hz. Another aspect of the quest for lowness concerns power-supply voltages and power dissipation. Two dual/quad families from Linear Technology, Models LT1078 and -1079, draw only 50 μA max per amplifier from a 5V supply and have offset voltages of 70 and 100 μV max, respectively. Prices are $2.80 and $3.50 (100). The new LT1178 and -1179 dual and quad devices draw only 18 μA max per section and have the same offset limits as the LT1078 and -1079. The LT1178 and -1179 cost $3.00 and $3.90, respectively.

Addressing the need for both lower power and reduced supply voltages, Precision Monolithics' recent OP-290 is a dual bipolar op amp that draws only 30 μA total from its supplies. Both its low power and its ±0.8 to ±18V supply range suit it for battery-powered applications. It has a 200-μV max offset voltage and minimum open-loop gains of 200,000V/V with ±1.5V supplies and 700,000V/V with ±15V supplies. The OP-290 costs $2.50 (100).

Two families of FET-input op amps from Texas Instruments meet the need for low power and input bias currents. The TLC031, -032, and -034 single, dual, and quad devices draw 280 μA max per amplifier from ±15V supplies and take 100-pA max input bias currents. The other JFET family is designed to operate from ±5 or ±15V supplies. The TLC051, -052, and -054 single, dual, and quad devices draw 3.2-, 5.6-, and 11.2-mA max supply currents, respectively, and require 200-pA max bias currents. Respective prices (100) for the TLC031, -032, and -034 are $0.49, $0.66, and $1.22; for the TLC051, -052, and -054, they're $0.63, $0.99, and $1.09.

Another new device from Texas Instruments draws 1.5 mA max from ±5V supplies. The $3.26 (100) TLC2201 is an FET-input amplifier that requires a 1-pA max input bias current. This low-noise device is specified at 18 nV/Hz$^{1/2}$ typ at 10 Hz, or 0.7 μV p-p typ over the band 0.1 to 10 Hz. Its dc specs include a 200-μV max offset voltage and a 400,000V/V min open-loop gain.

Final mention in this quest for lowness goes to Motorola. The company's low-noise, bipolar dual device called the MC33077 operates from ±2.5 to ±18V supplies and has an equivalent input noise of 6.6 nV/Hz$^{1/2}$ at 10 Hz. Intended for such high-volume markets as audio and automotive, the device boasts very low total

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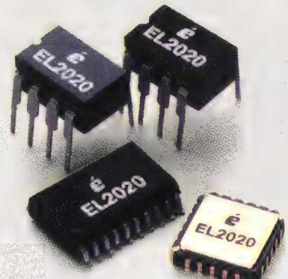

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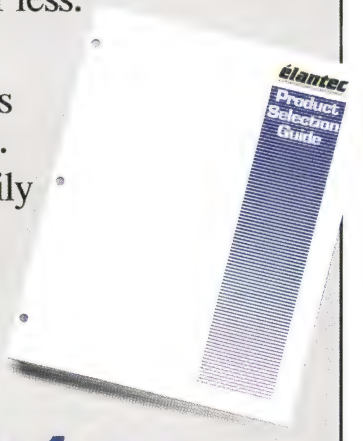

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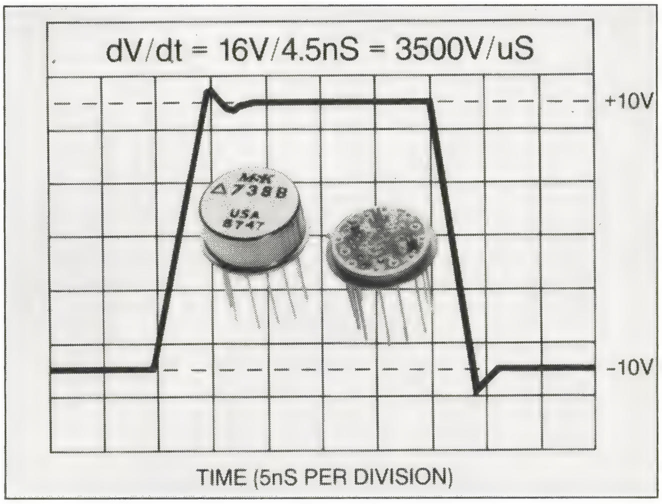
Emerging chopper-stabilized op amps drastically reduce the traditional problems of low-frequency noise and chopper-related aliasing of the input signal's frequency.



High speed doesn't necessarily entail poor dc performance. *Model MSK738 from MS Kennedy, for example, slews at 3200V/μsec and settles to within ±0.01% in 200 nsec. High speed notwithstanding, its dc specs earn the adjective "precision"—its offset-voltage and open-loop-gain limits are 75 μV and 100 dB, respectively.*

harmonic distortion—0.0007% typ at unity gain and 0.215% typ at a gain of 2000. Its price is $1.91 (100). Harmonic distortion of 0.003% typ at unity gain adorns the spec sheet of Motorola's soon-to-be-announced MC33272 and -33274 dual and quad families. These devices operate from ±1.5 to ±18V supplies and draw 2.5 mA max per amplifier. Both families have impressive high-frequency characteristics—their slew rates are 8 and 7V/μsec min, respectively.

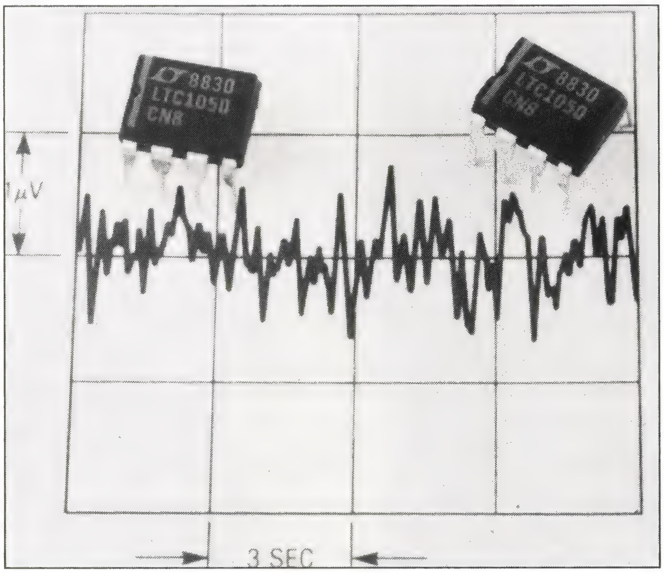
Amplifiers fabricated with CMOS processing dissipate low power and yield ultralow input bias currents. An example is Precision Monolithics' OP-80, which draws 325 μA from its ±5V supplies and requires a 2-pA max and 0.2-pA typ input bias current. The OP-80 is now available in a plastic DIP; this new version is called the OP-80GP. Prices start at $2 (100).

A wide range of CMOS op amps is available from Advanced Linear Devices Inc. A couple of recently available devices illustrate the low-voltage, low-bias capabilities of these CMOS units. Model ALD1706 is a single op amp that operates from a 5V supply; it's capable of using supplies that have a total span of 2 to 12V. Its input bias is 30 pA max, its supply current is 40 μV max, and its price is $0.89 (100). Model ALD4701 is a quad device that uses the same supplies and has the same bias currents as the ALD1706. It draws a 1-mA max supply current and costs $3.63 (100). Note that all of ALD's op amps are available as standard cells in the company's ASIC repertoire.

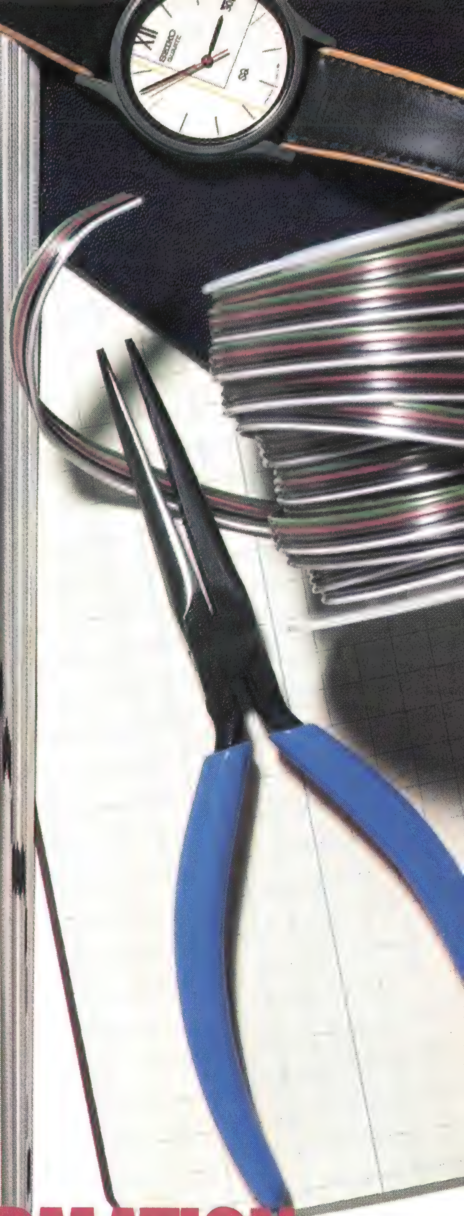
Let's jump abruptly from the quest for lowness in all specs to the efforts of manufacturers to get as much power as possible out of a given circuit volume. Such applications as low-impedance audio and ultrasonic transducers, pin drivers in ATE, and transformers and deflection coils demand a great deal of power. And, as in all systems, designers strive to minimize circuit-board area. One company that specializes in high-power hybrid amplifiers is Apex Microtechnology Corp.

Model PA04 from Apex is a rugged behemoth of an op amp housed in a TO-3 metal package. It operates from ±100V supplies and supplies output currents as high as 20A continuous. FET inputs keep bias currents to 20 pA max, and power-MOSFET outputs ensure freedom from secondary breakdown. Although capable of dissipating 200W internally, the amplifier is not sluggish—it slews at 40V/μsec min and has a typical gain-bandwidth product of 2 MHz.

A pair of boost pins in the PA04 allows the device's gain stages to operate at higher voltages than those the output devices operate from, thereby providing more drive to the output FETs. The resulting lower on-resistance yields about 8V more output swing and cuts the output-stage dissipation by as much as 100W. An additional feature is the amplifier's sleep mode, in which the quiescent current drops to 3 to 5 mA. The



Built-in capacitors and a high chopping frequency *grace the LT1050 chopper-stabilized op amp from Linear Technology Corp. Pin-compatible with industry-standard 7650 and 7652 types, the device chops at 2.5 kHz. Dedicated antialiasing circuitry eliminates aliasing at frequencies above the 1.25-kHz Nyquist frequency.*



ANALOG DEVICES

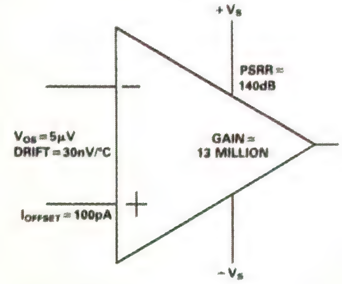
15µV max Offset Voltage Ultralow Drift Op Amp

AD707

FEATURES

Very High dc Precision
- 15µV max Offset Voltage
- 0.1µV/°C max Offset Voltage Drift
- 0.35µV p-p max Voltage Noise (0.1Hz to 10Hz)
- 8V/µV min Open-Loop Gain
- 0.32µV/V max CMRR
- 1µV/V max PSRR
- 1nA max Input Bias Current
- 1nA max Input Offset Current

Dual Version Available: AD708



PRODUCT DESCRIPTION

The AD707 is a low cost, high precision op amp with state-of-the-art performance that makes it ideal for a wide range of precision applications. The offset voltage spec of less than 15µV is outstanding for a bipolar op amp, as is the 1.0nA maximum input offset current. The top grade is the first bipolar monolithic op amp to offer a maximum offset voltage drift of 0.1µV/°C, and offset current drift and input bias current drift are both specified at 25pA/°C maximum.

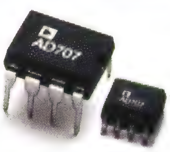
The AD707's open-loop gain is 8V/µV minimum over the full ±10V output range when driving a 1kΩ load. Maximum input voltage noise is 350nV p-p (0.1Hz to 10Hz). CMRR and PSRR are 130dB and 120dB minimum respectively.

The AD707 is available in versions specified over commercial, industrial and military temperature ranges. It is offered in 8-pin plastic mini-DIP, small outline, hermetic cerdip and hermetic TO-99 metal can packages. Chips and Mil Standard/883 parts are also available.

APPLICATION HIGHLIGHTS

1. The AD707's 13V/µV typical open-loop gain and 0.1µV/V typical common-mode rejection ratio make it ideal for precision instrumentation applications.
2. The precision of the AD707 makes tighter error budgets possible at a lower cost.
3. The low offset voltage drift and low noise of the AD707 allow the designer to amplify very small signals without sacrificing overall system performance.
4. The AD707 can be used where chopper amplifiers are required, but without the inherent noise and application problems.
5. The AD707 is an improved pin-for-pin replacement for the OP-07, OP-77 and the LT1001.

HERE'S THE MOST ACCURATE SOURCE OF INFORMATION ON THE WORLD'S MOST ACCURATE BIPOLAR OP AMP.



If your analog applications demand precision performance, then you should demand our new AD707 – the world's best dc precision op amp.

The AD707 is the first bipolar monolithic to offer a maximum offset voltage drift of only 0.1µV/°C, and 15µV maximum offset voltage. These features, combined with its ultralow 0.35µV p-p voltage noise, allow the AD707 to amplify extremely small signals without sacrificing system performance.

The AD707 also provides an open-loop gain of 13V/µV, which is the highest of any precision op amp, and unsurpassed 140dB CMRR and PSRR. So it's ideal for a wide range of precision applications, including instrumentation and automatic test equipment.

All this precision makes it easy for you to work within tight error budgets. And because the AD707 is available at a low cost, you can easily work within your design budget, too. Versions start at only $1.25 (in 100s).

For an even more accurate description of what the AD707 can do for you, call Applications Engineering at (617) 935-5565, Ext. 2628 or 2629.

Or write to Analog Devices, P.O. Box 9106, Norwood, MA 02062-9106.

ANALOG DEVICES

Analog Devices, Inc., One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106; Headquarters: (617) 329-4700; California: (714) 641-9391, (619) 268-4621, (408) 559-2037; Colorado: (719) 590-9952; Maryland: (301) 992-1994; Ohio: (614) 764-8795; Pennsylvania: (215) 643-7790; Texas: (214) 231-5094; Washington: (206) 251-9550; Austria: (222) 885504; Belgium: (3) 237 1672; Denmark: (2) 845800; France: (1) 4687-34-11; Holland: (1620) 81500; Israel: (052) 911415; Italy: (2) 6883831, (2) 6883832, (2) 6883833; Japan: (3) 263-6826; Sweden: (8) 282740; Switzerland: (22) 31 57 60; United Kingdom: (932) 232222; West Germany: (89) 570050

Standard-cell op amps in ASICs offer respectable specs and make it easy to combine analog and digital circuit blocks on a chip.

PA04 sells for $168 (100).

Another recent product from Apex is the PA21 dual op amp, which costs $21.50 (100). Useful for such applications as H-bridge motor drives, it operates from ±15V supplies and supplies currents as high as 3A from each amplifier. Housed in a TO-3-style package, the hybrid can dissipate 36W max. Its common-mode input-voltage range includes the negative rail, so it's amenable to operation from a single supply. The Model PA85 op amp from Apex works with ±15 to ±225V supplies and delivers 200 mA continuous to a load. Its FET inputs and outputs ensure low bias current and freedom from secondary breakdown. The device slews at 1000V/μsec typ and costs $99.50 (100).

A dual high-power op amp from Burr-Brown operates from ±35V supplies and supplies output currents to 5A continuous. Model OPA2541 has FET inputs that draw 50-pA max bias currents. Its bipolar output stage swings to within about 5V of the total supply span at an output current of 5A. Housed in a TO-3 package, the device slews at 6V/μsec min and costs $28.95 (100). Although it's not a high-power op amp, Burr-Brown's $5.15 (100) OPA445 also deserves mention for its extended voltage capability. It's an FET-input device that slews at 10V/μsec typ and operates from supply voltages as high as ±45V.

A dual power op amp from Motorola's French facility operates from ±15V and provides an output current to 1A. Model TCA0372 is available in 4- and 8-pin standard DIPs as well as in a plastic, single-in-line, medium-power package. Its bipolar output stage adds no deadband crossover distortion and provides an output swing about 2.5V lower than the supply span at 1A output current. The TCA0372 is priced at $1.25 (100).

As a final example of recently available power op amps, consider the CS-365 from Cherry Semiconductor. It operates from ±15V supplies and delivers 3A to a load. Housed in a plastic TO-220 package, it incorporates on-chip thermal and SOA (safe operating area) protection. The CS-365 slews at 8V/μsec typ and costs $1.44 (1000).

Off the beaten path

An op amp that has switchable inputs can be a useful device in such applications as synchronous demodulation as well as video and RF amplification. Two recent devices from Burr-Brown and Harris demonstrate the capabilities of these handy amplifiers. Burr-Brown's OPA675 and -676 (ECL- and TTL-compatible input switches, respectively) are wideband devices that settle to ±0.01% in 25 nsec typ. They have two independent differential-input sections that an ECL signal can switch between in 4 nsec typ; the TTL version switches in about 6 nsec. Both versions slew at 240V/μsec min and cost $22.80 (100).

Model HA-2410 from Harris is much slower than the OPA675 and -676, but it offers four independent, TTL-switchable differential-input sections. It slews at 8V/μsec typ; settling-time specs are still to be determined. Its offset voltage of 200 μV max and open-loop gain of 134 dB min qualify it as a precision amplifier. The HA-2410 sells for $7.80 (100).

It's worthy to note that op-amp standard cells are also available from several ASIC manufacturers. One such supplier is NCR (Fort Collins, CO), which has a large library of linear standard cells in its 1.5- and 2-μm repertoire. These are not wimpy, minimal op amps, either. An op-amp cell called the OA2001, for example, has a 2.5-MHz gain-bandwidth product and draws only a 300-μA supply current. A scaled-down version draws only 38 μA.

Other suppliers of op-amp standard cells include the already-mentioned Advanced Linear Devices, Gould Semiconductors (Santa Clara, CA), MCE Semiconductor (West Palm Beach, FL), Raytheon, Sierra Semiconductor (San Jose, CA), Linear Integrated Systems Inc (Fremont, CA), and Plessey Semiconductors (Scotts Valley, CA). EDN

Article Interest Quotient (Circle One)
High 497 Medium 498 Low 499

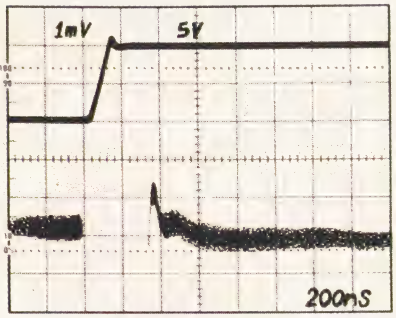
ANALOG DEVICES

500ns Settling BiFET Op Amp

AD744

FEATURES
Fast Settling:
500ns to 0.01% for 10V Step
1.5μs to 0.0025% for 10V Step
Slew Rate: 75V/μs
Total Harmonic Distortion (THD): 0.0003%
>1000pF Capacitive Load Drive Capability with 10V/μs Slew Rate

Input Offset Voltage: 0.25mV max
Input Offset Drift: 3μV/°C max
Open Loop Gain: 250V/mV min
Noise: 4μV p-p max, 0.1Hz to 10Hz



AD744 Settling Characteristics 0 to + 10V Step

PRODUCT DESCRIPTION

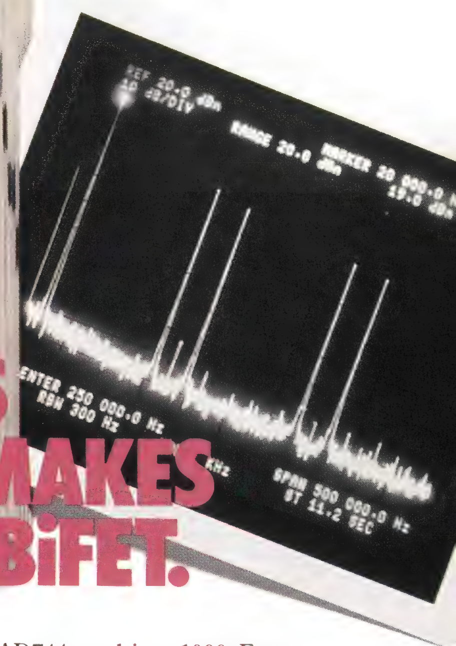
The AD744 makes a breakthrough in the high speed BiFET market by offering guaranteed maximum settling to 0.01% in 750ns. It also offers the excellent dc characteristics of the AD711 BiFET family with enhanced slew rate, bandwidth and load driving capability.

The single-pole response of the AD744 provides fast settling: 500ns to 0.01% typically, and 750ns maximum. This feature, combined with high dc precision, makes the AD744 suitable for use as a buffer amplifier for 12-, 14- and 16-bit DACs and ADCs. Furthermore, the AD744's low total harmonic distortion (THD) level of 0.0003%, low noise and gain bandwidth product of 13MHz make it an ideal amplifier for demanding audio applications. It is also an excellent choice for high speed instrumentation amplifiers and for use in active filters.

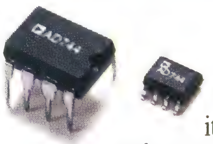
The AD744 offers optional custom compensation for additional design flexibility. This external compensation allows the AD744 to drive capacitive loads up to 2000pF and greater with full stability, making the AD744 outstanding for use as a coaxial cable driver. Alternatively, external decompensation may be used to increase the gain bandwidth of the AD744 to over 200MHz at high gains. This makes the AD744 ideal for use as an ac preamp in digital signal processing (DSP) front ends.

PRODUCT HIGHLIGHTS

1. The AD744 offers exceptional dynamic response. It settles to 0.01% in 500ns and has a 100% tested minimum slew rate of 50V/μs.
2. The combination of Analog Devices' advanced processing technology, laser wafer drift trimming and well-matched ion-implanted JFETs provide outstanding dc precision. Input offset voltage, input bias current and input offset current are specified in the warmed-up condition and are 100% tested.
3. The AD744 has a guaranteed and tested maximum voltage noise of 4μV p-p, 0.1 to 10Hz.
4. The AD744 is a high speed BiFET op amp that offers excellent performance at competitive prices.



THIS PAGE SETTLES THE QUESTION OF WHO MAKES THE FASTEST SETTLING BiFET.



A lot of companies say they have fast-settling, high-performance BiFET amps. But our AD744 settles to 0.01% in 500ns and to 0.0025% in 1.5μs – making it the world's fastest-settling, highest-performance BiFET.

This superior settling, combined with excellent dc performance, makes the AD744 unbeatable for active filters, and for buffering DACs and ADCs up to 16 bits.

The AD744, with a total harmonic distortion of just 0.0003%, low noise, a clean pulse response, and a gain bandwidth product of up to 200MHz, is also ideal for digital signal processing and audio applications.

If you work in communications, you'll appreciate the AD744's ability to drive loads greater than 2000pF with full stability. And the fact that the AD744 can drive a 1000pF cap load while maintaining a slew rate of 10V/μs.

The AD744 isn't our only outstanding BiFET, either. The AD711 single, AD712 dual, and soon the AD713 quad, settle in 1μs with the same high resolution as the AD744. If low power with precision is critical, try our AD548 single or AD648 dual.

Whichever BiFET your application requires, you'll find our products deliver excellent performance at an excellent price. In fact, they're some of the most competitively priced BiFETs available today.

If you'd like more proof on why we can say we make the best BiFETs, call your nearest Analog Devices sales office.

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ANALOG DEVICES

AD840 Series

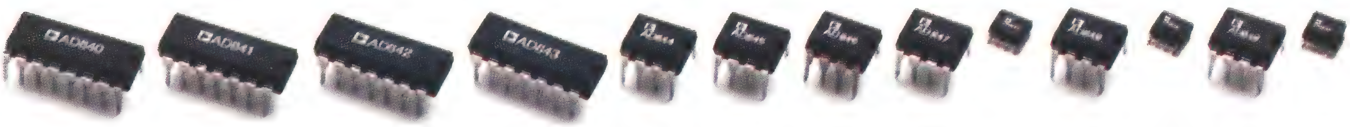
	AD840	AD841	AD842	AD843	AD844
Gain Bandwidth Min Stable Gain	400MHz 10	40MHz Unity	80MHz 2	35MHz Unity	60 to 430MHz Unity
Settling Time (10V Step)	100ns to 0.01%	110ns to 0.01%	100ns to 0.01%	110ns to 0.01%	100ns to 0.05%
Slew Rate	400V/μs	300V/μs	375V/μs	300V/μs	to 2,000V/μs
Quiescent Current (max)	12mA	12mA	14mA	12mA	6.5mA
Comments	HA2540 Improved Replacement	50mA min Output Current	100mA min Output Current	FET-Input, Replaces FET- Input Hybrids	Current Feedback, 2nV/√Hz Noise at 1kHz

THE REVOLUTION IN
STARTS R

Introducing our AD840 Series with ten new op amps – and the start of a revolution. Because now you can go to just one vendor and get more high speed op amps with higher precision and lower power than from anywhere else.

The AD840 Series, which includes high accuracy, low noise, low cost, FET-input and current-feedback amps, is the result of a major breakthrough we've made in analog process technology. A breakthrough that has not only led to such diversity, but has also made each op amp a performance leader.

For example, several of the products in the AD840 Series offer gain-bandwidths greater than 400MHz, while others offer slew rates up to 2,000V/μs. And all AD840 products offer precision at high speeds, with unprecedented settling time performance as fast as 100ns to 0.01%



AD845	AD846	AD847	AD848	AD849	
16MHz Unity	46 to 600MHz Unity	50MHz Unity	175MHz 5	750MHz 25	Gain Bandwidth Min Stable Gain
350ns to 0.01%	100ns to 0.01%	120ns to 0.1%	100ns to 0.1%	80ns to 0.1%	Settling Time (10V Step)
100V/μs	450V/μs	300V/μs	300V/μs	300V/μs	Slew Rate
12mA	6mA	5.7mA	5.7mA	5.7mA	Quiescent Current (max)
FET-Input, Drives Cap Loads	Current Feedback, 75μV max Offset Voltage	Excellent Flash ADC Buffer	Stable into any Cap Load	Low Noise Pre-Amp	Comments

(10V step) and offset voltage down to 75μV maximum.

This high performance isn't at the expense of power. In fact, each AD840 product consumes 25-50% less power than comparable amps, without sacrificing load drive current. Plus all parts operate with ±15V or ±5V supplies.

The high performance doesn't come at a high cost, either. You'll find that whether you use the AD840 Series op amps to bring a new standard of performance to your designs, or as replacements for industry standards, they're all competitively priced.

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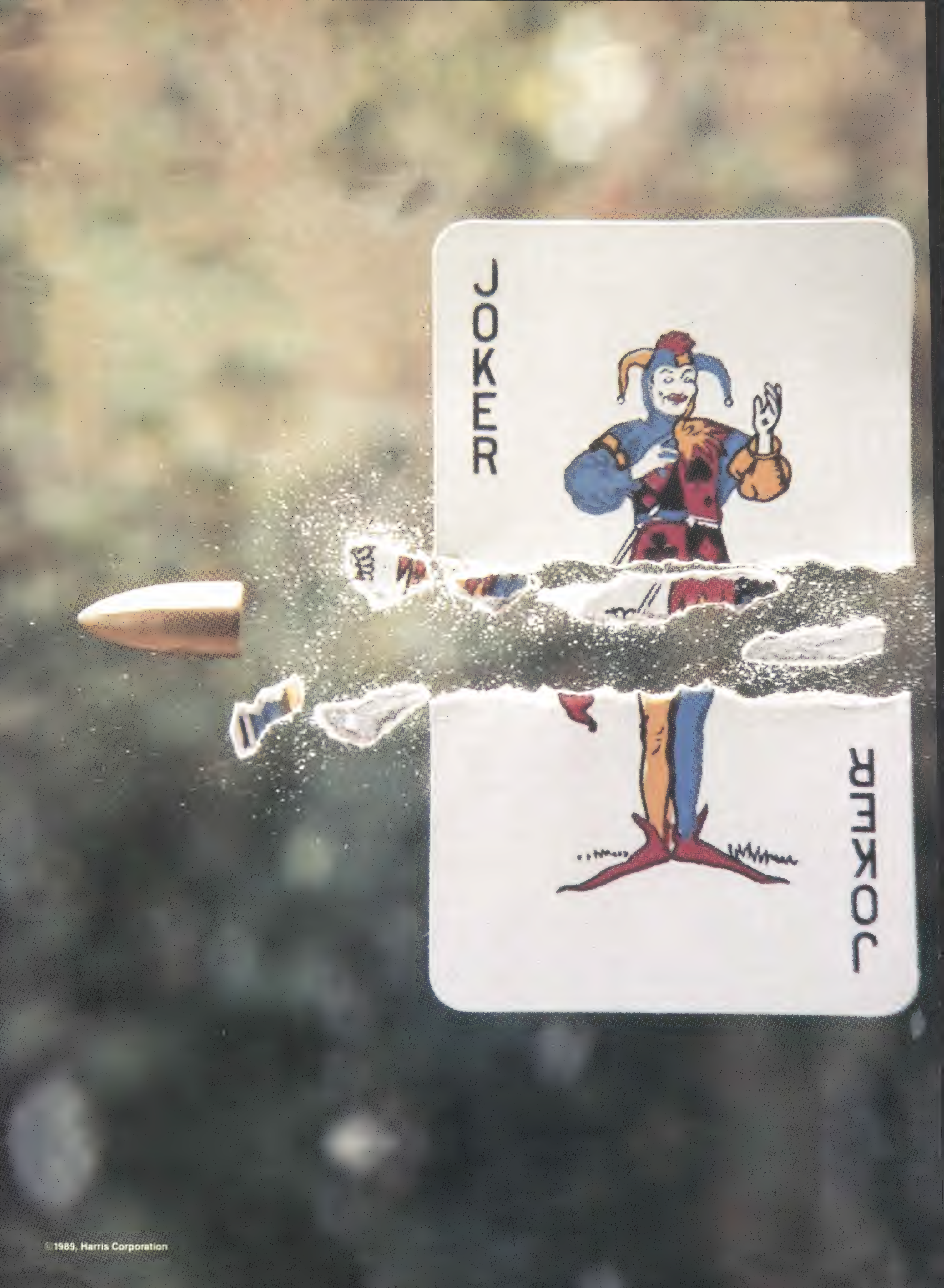
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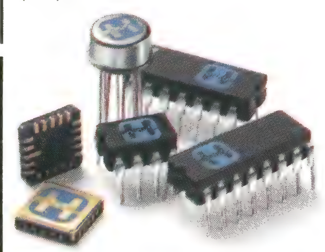
Max Offset Voltage	μV	700	200	25	100	300	25
Settling Time	μSec	1.5	2.0	14.0	13.0	1.0	0.4
Offset Drift	μV/°C	0.5	3.0	0.1	0.3	2.0	0.2
Gain	V/μV	2.5	5.0	30.0	3.0	0.6	1.8
Noise	nV/Hz	3.4	6.0	3.8	7.0	10.0	3.0
Slew Rate	V/μSec	20.0	8.0	0.8	7.0	8.0	35.0
Bandwidth	MHz	35.0	8.0	1.4	4.0	8.0	10
Supply Current	mA	8.0	4.0	1.2	6.5	1.9	3.0
Packages	LCC	•	•	•	•	•	
	Cerdip	•	•	•	•	•	•
	TO-99			•		•	

All specs typical.



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CIRCLE NO 157

High-resolution ADCs simplify system design in DSP applications

You can use high-resolution A/D converters to sample and quantize analog signals in DSP applications. These data converters simplify system design because they incorporate onboard sample-and-hold amplifiers and fast processor interfaces.

John Sylvan, Bob Malone, John Reidy, Paul Errico, *Analog Devices Inc*

The basic task of a sampling A/D converter is to sample and quantize an ac input signal. Sampling ADCs combine an A/D converter with an onboard sample-and-hold amplifier on a single chip (or in a single hybrid package). As a result, manufacturers can test and specify all ac and dc parameters, including dynamic specifications such as signal-to-noise ratio (SNR), total harmonic distortion (THD) and intermodulation distortion (IMD). Knowing these specifications, engineers can easily design circuits to digitize high-speed analog waveforms.

To fully benefit from these features and maximize your circuit's performance, you must select a sampling ADC that complements your processor and meets the requirements of your application (see **box,** "Choose the right sampling ADC"). The latest generation of digital signal processors (DSPs) and general-purpose microprocessors places high demands on processor interfaces. Because these processors have fast cycle times, you have to use converters with fast data-access times. If your converter can't keep up with the processor's data transfer rate, you must employ wait states or wait-state logic in your circuit design. Furthermore, real-time operation forces you to examine ways to reduce interrupt overhead. Every time the processor has to service an interrupt, it consumes several clock cycles. You may want to consider using one of the new converters that includes FIFO memory to reduce the frequency of processor interrupts. In addition, you must decide whether to use a parallel or serial interface in your design. A handful of sampling A/D converters simplify this decision because they combine serial and parallel capabilities on a single chip.

Reduce complexity with a serial interface

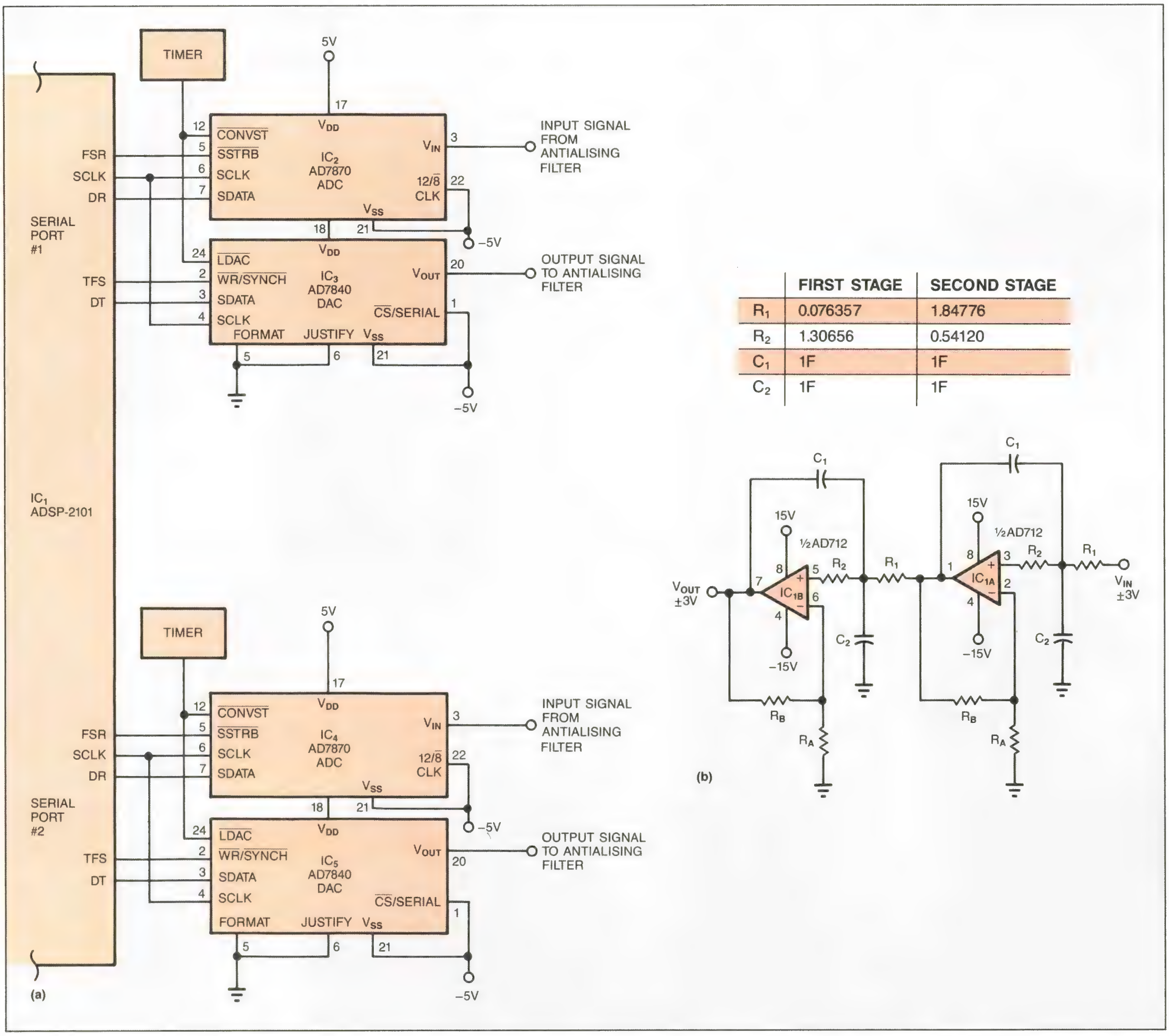
For most DSP system designs, you usually first decide what processor you plan to use and then select the proper ADC to accompany it. You rarely put the cart in front of the horse by permitting an ADC to restrict what processor you use. The I/O port structure of the processor, however, can restrict the selection of converters. Many DSPs have a limited number of ports and therefore use a serial port to communicate with peripheral devices. Because of this I/O constraint, you must either design a discrete circuit for parallel-to-serial conversion or find an ADC with a serial port.

When you design a DSP system, you should first decide what processor to use and then choose the appropriate ADC.

However, if the DSP and the ADC have the proper on-chip logic, a serial interface can be clean and simple.

If you use a serial interface, the processor must be able to accept the data as it becomes available from the A/D converter. For example, a successive-approximation ADC produces a bit—from the MSB to the LSB—on each clock cycle. For this reason, highly efficient data transfer can occur between a single ADC and a single serial port.

The two-channel vocoder shown in **Fig 1a** illustrates the simplicity found in many serial interfaces. This circuit uses two serial I/O ports, two 12- or 14-bit A/D converters, and two 14-bit D/A converters for real-time speech compression. Each converter requires only three interface lines. Because there are few high-frequency lines that connect the converters to the processor, the circuit minimizes on-chip digital feedthrough in the data converters. In addition, if you have to install galvanic isolation, you need to add only a few inexpensive optical isolators to the serial interface.



	FIRST STAGE	SECOND STAGE
R_1	0.076357	1.84776
R_2	1.30656	0.54120
C_1	1F	1F
C_2	1F	1F

***Fig 1—Serial data communications (a) simplify the interface** between data converters and a signal processor in voice-band applications. With oversampling techniques, a fourth-order Butterworth filter **(b)** eliminates the need for a high-order filter with a steep roll-off.*

Choose the right sampling ADC

The selection of available sampling A/D converters includes a host of devices with different features and capabilities. Their resolutions, for example, can range from 4- to over 18-bits. Although all sampling A/D converters include one key attribute—an internal S/H amplifier—some devices also include a buried-zener reference, a FIFO buffer, and other features. When selecting a sampling ADC, you must carefully evaluate the various types of converters and their respective options to find the device that best suits your application. **Table A** shows some of the attributes of eight high-resolution, 12- and 14-bit converters.

Additional features can include an internal voltage reference and a filter, which reduce the number of support components that you have to add to your pc board. You must examine the component's data sheet to ensure that the performance of the internal reference and the filter meet your system's requirements. For example, if you're incorporating autocalibration into your design, you need a high-accuracy, low-drift voltage reference.

Another criterion for selecting the appropriate data converter is whether dc specifications are relevant to your application. In dynamic-signal analysis, specifications such as total harmonic distortion, signal-to-noise ratio and intermodulation distortion predict the performance of the circuit better than specifications such as integral and differential linearity errors. However, you don't necessarily have to trade off good dc performance for good ac performance; all the converters listed in **Table A** guarantee 12-bit dc performance over their respective operating temperatures. If you aren't concerned with dc specs, consider two of the A/D converters in the **Table A**—the AD678 and the AD679. They are available as ac-specified-only parts under the guise of the AD1678 and the AD1679.

Because many DSP applications involve real-time signal processing, converter interface formats and speed are crucial. Slow bus-access times (parallel-data transfers) require that you either insert wait states into your software or add wait-state logic. Because many DSPs now offer cycle times under 100 nsec, you need a converter that has a bus-access time of under 25 nsec to totally eliminate wait states. Some converters that have serial I/O capability can relax these constraints.

The sampling A/D converters' high conversion rates and the need to maintain control of sampling intervals increase the processor's overhead. You can reduce this overhead, however, by using devices that have onboard FIFO buffers. The FIFO buffer stores the results of several conversions before it requires a read operation by the processor. For example, an A/D converter with a 32-word-deep FIFO and an 8-μsec conversion time requires a processor read only every 256 μsec. Likewise, a monolithic A/D converter with an 8-word FIFO needs serving only every 64 μsec.

TABLE A—CHARACTERISTICS OF HIGH-RESOLUTION ADCs

MODEL	RESOLUTION (BITS)	SAMPLE RATE (k SAMPLES/SEC)	INPUT BANDWIDTH (kHz)	NUMBER OF INPUT CHANNELS	T/H AMPLIFIER	REFERENCE	FILTER	SERIAL DATA PORT	PARALLEL DATA PORT	FIFO LENGTH (WORDS)	BUS ACCESS TIME (nSEC)
AD678	12	200	500	1	✓	✓			✓		100
AD7870	12	100	500	1	✓	✓		✓	✓		57
AD7878	12	100	500	1	✓	✓			✓	8	41
AD1332	12	125	125	1	✓	✓	✓		✓	32	15
AD1334	12	65	235	4	✓[2]	✓			✓	32	15
AD679	14	100	500	1	✓	✓			✓		100
AD7871	14	100	500	1	✓	✓		✓	✓		60
AD7872	14	100	500	1	✓	✓		✓			60

NOTES:
1. SINGLE-CHANNEL MODE; 28k SAMPLES/SEC FOR 4-CHANNEL MODE
2. FOUR INTERNAL S/H AMPLIFIERS FOR SIMULTANEOUS SAMPLING

With a serial interface, the DSP must be able to accept data as it becomes available from the ADC.

The serial 12-bit AD7870 in **Fig 1a** is a CMOS A/D converter with an internal T/H amplifier and a buried-zener voltage reference. The device's acquisition time is 2 μsec, and its conversion time is 8 μsec ±0.01%. If you need higher resolution, you can use the AD7871 or the AD7872. These 14-bit converters have the same interfaces and conversion rates as the AD7870. A companion D/A converter, the AD7840, extends resolution to 14-bits and has many of the same characteristics as the A/D converters, including an internal reference. The DAC's settling time is 3 μsec to ±1 LSB. The A/D and D/A converters operate from ±5V supplies, and their input voltage is ±3V. This low input range reduces the slew-rate and settling-time requirements of both the internal and external circuitry.

The serial interface requires three timing signals: a frame synchronization pulse, a serial clock to move the data between the processor and the converters, and a precise timer to generate the conversion-start and output-update commands. You can use the internal clock in the A/D converter to produce the serial clock for each input and output channel. Employ a precise timer to generate the conversion-start command, $\overline{\text{CONVST}}$, and the load-output register, $\overline{\text{LDAC}}$. Finally, you can use the $\overline{\text{FLGOUT}}$ from the ADSP-2101 in place of an external timer.

The processor and the ADC are responsible for generating the proper framing signals. In this application, after the ADC's S/H amplifiers go into the hold mode, the $\overline{\text{SSTRB}}$ goes low, thereby delivering framing signals for the output serial data. To send data to the D/A converters, the processor sends synchronization pulses when its transmit register has valid output data.

The data transmissions between the data converters and the processor are 16-bit words. The A/D converter inserts four leading zeros followed by the MSB and the other conversion data. The D/A converter accepts a similar 16-bit data word, which is then manipulated by the internal on-chip logic. If you tie the Format and the Justify pins to ground, you "left-justify" the data word and tell the converter to ignore the first two bits.

One drawback of serial-data transfer is that you must read the conversion results after each conversion. The processor spends a good fraction of its overhead trans-

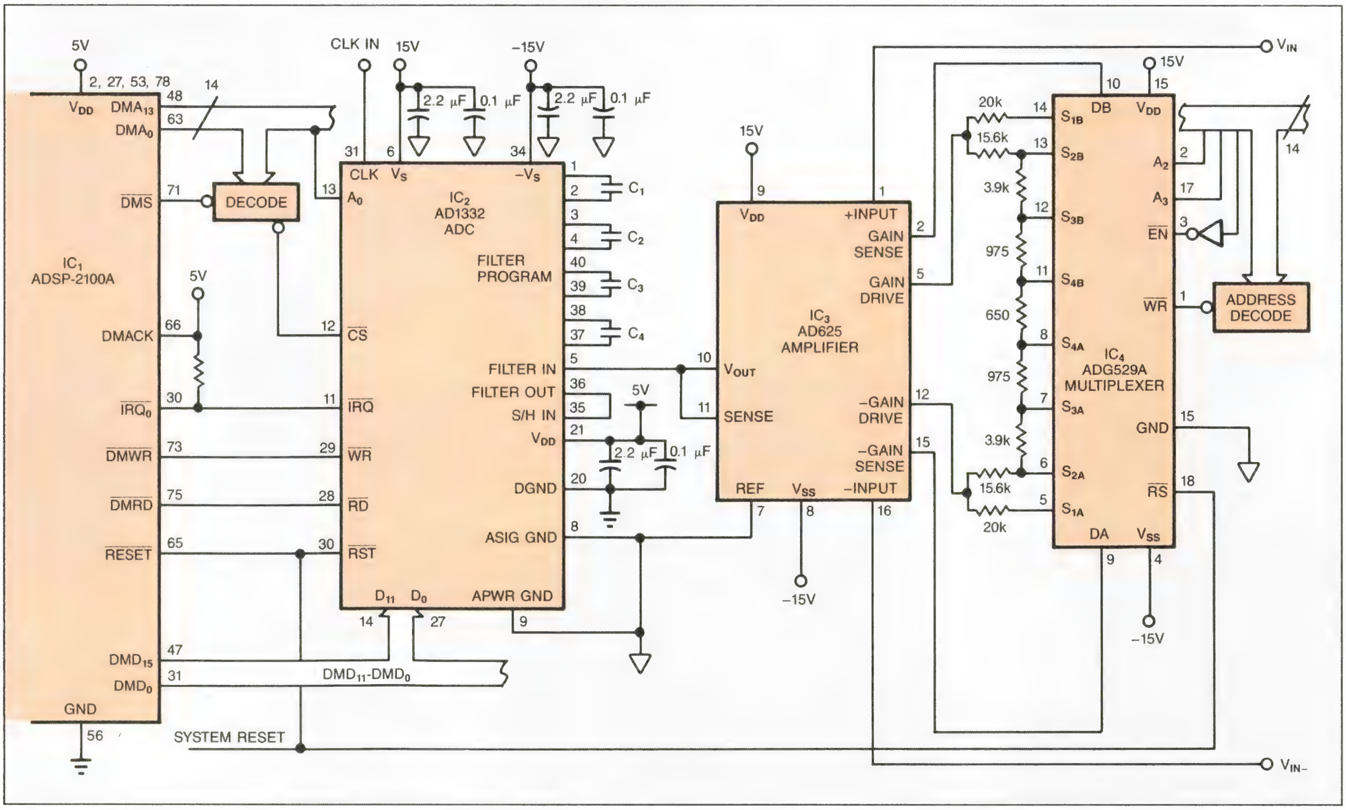


Fig 2—When a sampling A/D converter flags an overrange condition, a processor can adjust the input signal range with a software-programmable instrumentation amplifier.

mitting and receiving data; the resulting reduction in throughput can limit the system's performance.

To avoid bogging down the processor, use a device that includes autobuffering features. For example, each serial port on IC_1 has an internal receive register and transmit register. At the end of the serial-data transfer, the processor steals a single cycle to move the data from the receive register to a preassigned circular buffer in data memory (internal or external). An interrupt occurs only after the buffer is full. A similar process occurs on the output channel. The processor moves data from a predefined transmit buffer to the transmit register in one clock cycle. When the output buffer is empty, the processor generates an interrupt and seeks new output data.

Oversample input signals

One of the few analog design tasks that you must perform when using a sampling converter is building an antialiasing filter. A converter that is operating at or near its Nyquist rate requires a high-order filter with a steep roll-off (ninth-order filters or greater are commonly used). To simplify the filter design, you can use oversampling techniques. In many cases, it's worth the effort and the cost to use an A/D converter that has a sampling rate four to eight times the circuit's input bandwidth. (You need a sampling rate twice the input frequency to satisfy Nyquist criteria.) If you use such a converter, you can replace a complex filter with a relatively simple design.

The fourth-order Butterworth filter shown in **Fig 1b** illustrates the benefits of oversampling. This design is fairly simple and inexpensive to construct and requires only two op amps per channel. You can use a decimation filter algorithm to reduce oversampled data to the effective sampling rate of 8 kHz. In a similar fashion, a digital interpolation scheme (similar to those used to oversample compact-disk players) can generate the 32-kHz output sample rate from the 8 kHz of voice-band data.

This fourth-order, lowpass Butterworth filter features a Sallen & Key configuration. You can cascade the two stages to achieve the fourth-order response. To determine the appropriate values of the resistors and the capacitors, use the table included in **Fig 1b**. Multiply the resistor values by 10^8 and divide the capacitor values by 10^8. To calculate the cutoff frequency, divide the resistor values by 2Π. Adjust the values of

Synchronous vs asynchronous conversion

Unlike most dc applications for A/D converters, signal processing of ac waveforms demands that you maintain tight control of the time intervals between samples.

Many dc applications use the processor to initiate the conversion and use the A/D converter to generate an interrupt when the conversion results are ready. Because the time period that the circuit takes to respond to each interrupt varies, the time intervals between samples also vary. This variation appears as excessive sample-and-hold uncertainty and results in diminished SNR performance in ac signal processing. A timer or a clock that controls sampling independent of the processor can alleviate this problem.

Some sampling A/D converters that run asynchronously to the processor permit it to read data at any time, even during a conversion (although the data readout will be the results of the previous conversion). Other converters delay the read operations that occur during sensitive operations. A converter-status line informs the processor of the need to read valid data. The processor can schedule its read at its own convenience, as long as it removes the data before the A/D converter finishes the next conversion. To give the processor even more leeway, some ADCs include an internal FIFO buffer. The FIFO buffer can store the results of several successive conversions before it needs to interrupt the host processor to transfer data.

The major problem with asynchronous operation is that you must make sure that no conflict exists between internal converter operations and reads and writes to the device. If a conflict occurs, you must derive the converter's clock from the processor's clock signal. The timer for the conversion start, however, can remain asynchronous. In some devices, you can also make the FIFO memory appear as random access memory to the processor, thereby alleviating the need to synchronize the data converter and processor.

You should consider using one of the new converters that includes FIFO memory to reduce the frequency of processor interrupts.

resistors R_A and R_B to set the magnitude scaling. For example, for a gain of two, R_A and R_B should be equal.

When you have multiple ADCs or plan to use a DSP that doesn't have a serial port, you must evaluate ADCs that have parallel data ports. A parallel bus eliminates the potential for contention when two or more converters share a single serial port on a processor. It also allows increased flexibility when you add other peripherals such as D/A converters, programmable gain amplifiers, or multiplexers. The drawback of using a parallel interface, however, is that you need more high-speed traces running across your board, and you must use sampling converters that have high-speed interfaces.

You must look at the A/D converters' data-access times to make sure that the devices are compatible with the processor you've selected. The newest monolithic devices have data access times of 40 to 60 nsec. You can connect one of these high-speed ADCs directly to a processor that has a 100-nsec or greater instruction cycle without adding wait-state logic. To achieve faster bus-access times, however, you need to use a hybrid A/D converter. The processor in **Fig 2**'s vibration-analysis circuit can read conversion results directly from the ADC at its full 12½-MHz clock rate. The typical access time for the ADC is only 7 nsec, which is well below the processor's 25-nsec read time.

The sampling converter (IC_2 in **Fig 2**) exemplifies the trend toward "complete" sampling A/D converters. One package includes a fourth-order Butterworth filter, an S/H amplifier, a 12-bit A/D converter, a FIFO buffer, and a timing generator. Because the AD1332 is a self-contained unit, all you must do in many applications is connect your analog input signal, and have the processor execute a simple read operation to remove the data.

The interface between the processor and IC_2 is simple; it requires only address-decode logic. In fact, because the ADC has an internal 32-word FIFO and provides asynchronous operation, the interface looks

Minimize the effects of digital feedthrough

Because a 12-bit A/D converter can have bit decisions as low as 1.46 μV (±3V full scale), digital bus noise can easily overpower the low-level analog input signal. With asynchronous data conversion, it's difficult to prevent the processor from executing a read or write during sensitive converter operations. Hybrid devices, such as the AD1332 and the AD1334, are inherently isolated from the digital bus because of their multichip construction. However, a number of feedthrough-reduction techniques can alleviate this problem even in monolithic converters.

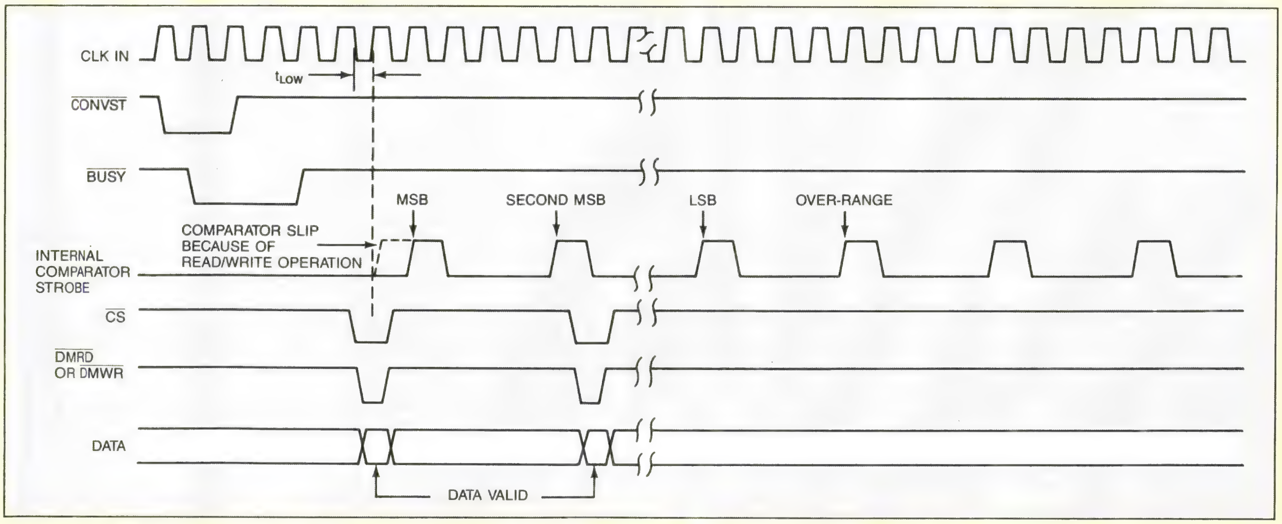


***Fig A—This timing diagram for a comparator-slip design** extends the bit-decision point by one clock cycle during a data-read operation.*

like high-speed memory to the processor. In other words, you won't have to redesign your analog circuitry when upgrading to a faster processor. Moreover, because the multichip design offers inherent isolation, you don't have to worry about digital bus noise reducing the conversion accuracy.

When the FIFO buffer stores 32 conversion results, the ADC generates an interrupt, thereby alerting the processor that the FIFO is full. At that point, the ADSP-2100A reads data from the FIFO and either processes it or stores it temporarily in RAM. You can also program the converter to generate an interrupt when the FIFO is half full or after every conversion (FIFO bypassed). You should use the half-full mode if the processor is unable to service the converter after it fills its last FIFO register. The ADC continues to fill the remaining 16 memory locations, and the processor can read the data anytime before the FIFO overflows.

In addition to having extensive on-chip logic, IC_2 has an onboard fourth-order Butterworth filter. Because it isn't in the converter's input path, this filter is optional. The internal filter is an RC active simulation of an LC "prototype" and is insensitive to component variations. Its actual response for 25- and 50-kHz cutoff frequencies is the same as the Butterworth filter's characteristic roll-off—80 dB/decade.

You should use four equal-value capacitors (C_1, C_2, C_3, and C_4) to set the cutoff frequency according to the equation: $F_C = 25$ kHz/C, where C is the capacitor value in nF. Use low-dissipation, ceramic, metallized polycarbonate or polystyrene capacitors. If you don't need the filter, connect pins 2, 3, 38, and 39 to the analog-signal ground at pin 8.

Because over-range data introduces nonlinearities to any signal analysis, you must ensure that the input signal level remains below the ADC's full-scale range or that the circuit flags any over-range condition for the processor. You can program IC_2 to generate an interrupt when the input voltage exceeds its ±5V in-

One feedthrough-reduction technique is to postpone sensitive comparator bit-decisions during noisy reads and writes.

Fig A shows a "comparator-slip" technique used in the AD7878 (**Fig B**) to delay delicate comparator decisions during reads and writes. The internal comparator strobe is gated with both data-memory read ($\overline{\text{DMRD}}$) and data-memory write ($\overline{\text{DMRW}}$). Normally, as shown in **Fig A**, CONSVT goes high, and the MSB decision occurs 25 nsec after the fourth rising edge of $\overline{\text{CLK IN}}$. Because either $\overline{\text{DMRD}}$ or $\overline{\text{DMRW}}$ is low prior to the fourth rising-edge of CLK IN, the comparator strobe is delayed until $\overline{\text{DMRD}}$ or $\overline{\text{DMRW}}$ returns high. The converter can accommodate as many as 16 reads and 1 write during a conversion routine; therefore, the delay effectively extends the conversion time from 7 to 9.12 µsec if there's slippage of one CLK IN cycle for each read or write operation.

Converters such as the AD678 and the AD679 also use error-correction techniques to minimize the effects of digital feedthrough. The device's recursive subranging architecture uses four or five sequential 3-bit conversions and error corrections on each cycle to generate a 12-bit or 14-bit result.

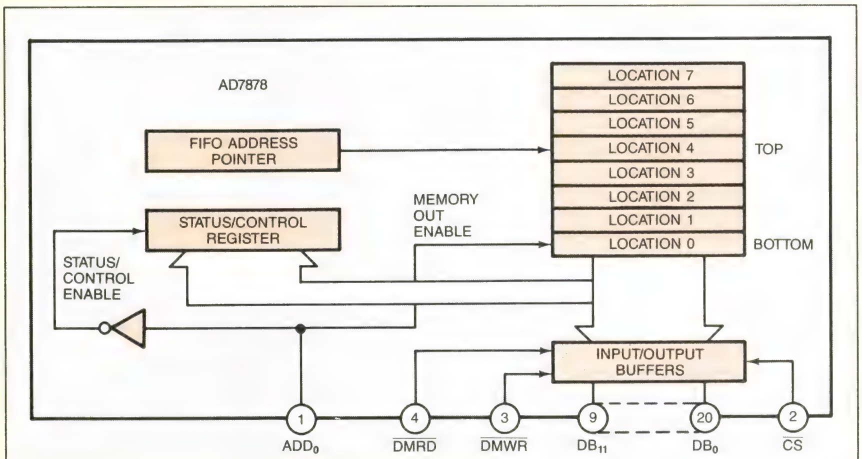


Fig B—The eight FIFO buffers *in this device store the results of eight conversions, eliminating the need for a data-read after every conversion.*

When operating a converter near its Nyquist rate, you must the use an antialiasing filter to keep unwanted signals out of the conversion process.

put range. When this occurs, the processor can clear the interrupt by writing to the converter's control register and automatically reset the gain of the front-end amplifier.

Dynamic gain switching requires a software-programmable gain amplifier (SPGA). If the system must handle differential signals with large common-mode voltages, you should use a wide-bandwidth instrumentation amplifier as the gain block.

To construct an SPGA, you need to add only a low-cost CMOS multiplexer and a few external resistors to **Fig 2**'s instrumentation amplifier, IC_3. Connect the amplifier's gain-sense and drive pins to the ends of the external resistor ladder. This connection removes the mulitplexer's on-resistance from the signal path, thereby transforming it to a nullable offset error and reducing gain errors and gain drift. Make sure that you ground all unused multiplexer pins; floating terminals can create random conversion errors.

The resistor values shown in the circuit produce binary gains of 1, 4, 16, and 64. To calculate the amplifier gain, use the equation: $gain=(2R_F/R_G)+1$. The value of R_G equals the sum of the resistor values between the two gain-sense pins; R_F equals the resistance value between the gain-sense and drive pins. For gains to 500, consider replacing the discrete circuitry with a hybrid SPGA such as the AD365.

One common application for high-resolution sampling converters is in full-duplex 9600- or 19200-baud modems. High-end V.32 and V.33 modems require extensive signal processing for echo cancellation, modulation, demodulation, and scrambling and unscrambling of data. Except for the receive and transmit filters (**Fig 3**), you can partition your system to perform all necessary signal processing in the digital domain. The modem transmitter synchronizes the incoming baseband data to the transmit clock, scrambles it, modulates it, and then sends the passband data to the ADC. The receive section digitizes the passband signals, implements echo cancellation, and filters and unscrambles the data to recover the baseband signal.

When you use a modem, one key design goal is to reduce the bit-error rate of the digital transmission. One way to achieve this—other than through extensive error correction—is to improve the ac performance of the analog circuitry. To do so, you should examine the SNR, THD, and IMD specs of any data converter you plan to use.

To improve SNR performance, use 14-bit ADCs and DACs instead of 12-bit devices. Of course, the converters must have specifications commensurate with their high resolution; many 14-bit data converters guarantee only 12-bit performance.

Fig 4 shows the filtering and conversion hardware for a V.32 or V.33 modem. The 14-bit A/D and D/A converters in the circuit deliver an SNR of 82 dB at a

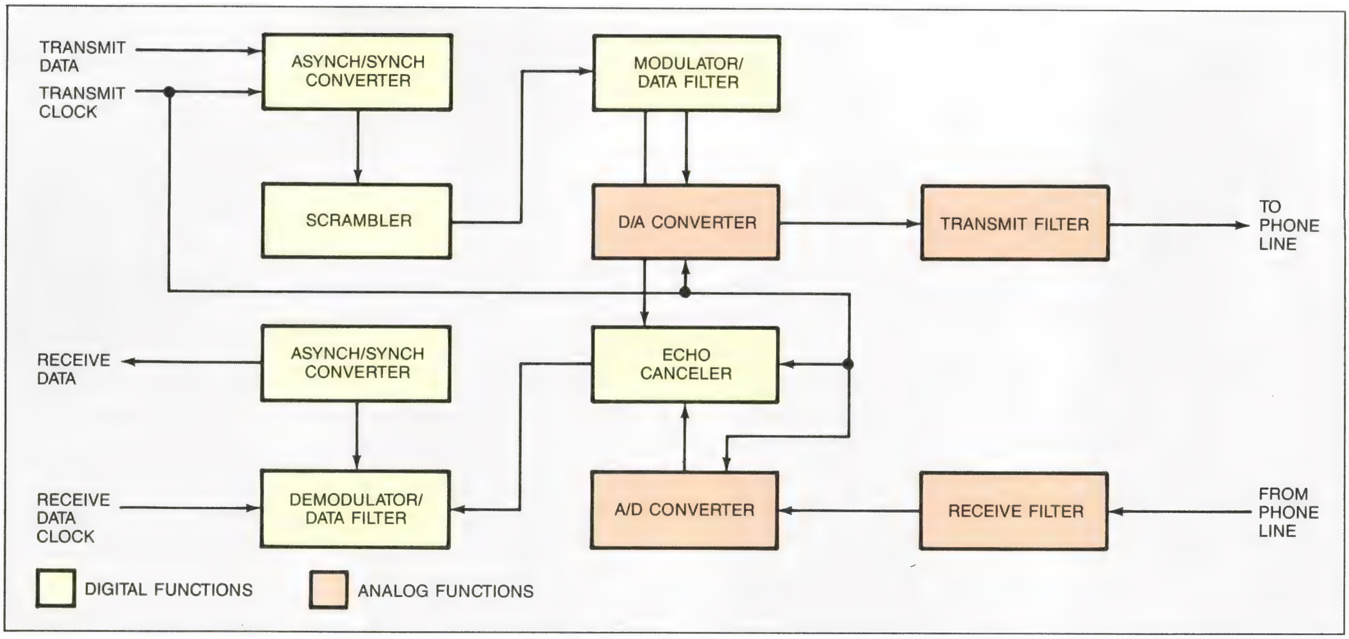


Fig 3—High-end V.32 and V.33 modems *require extensive signal processing to minimize bit-error rates.*

10-kHz signal bandwidth and a 100-kHz sampling rate. Like the A/D converters in previous designs, the AD7871 converter has an onboard S/H amplifier and a reference.

The receive filter, IC_4, combines a seventh-order lowpass, switched-capacitor filter and a second-order continuous-time filter that has a cutoff frequency of 3.5 kHz. The transmit filter, IC_5, is a high-order bandpass filter with a lower cutoff frequency of 180 Hz and an upper cutoff frequency of 3.5 kHz. Both the receive and transmit filters have a THD spec of better than -75 dB, a stopband rejection of -70 dB, and a passband ripple of ± 0.2 dB.

The filters and the data converters operate with full-scale input and output ranges of ± 3V. To accommodate other voltage ranges, you can attenuate the output of the transmit filter and amplify the input of the receive filter with their on-chip programmable gain amplifiers. Use pins DB_2 through DB_7 on IC_5 to set the attenuation from 0 to 38 dB. In a similar manner, you can use pins DB_0 through DB_7 to program the gain of the receive filter, IC_4, in 3-dB increments.

Because high-speed modems use quadrature amplitude modulation, synchronized timing is critical. Errors in the conversion timing produce phase errors and create distortion in the frequency domain, which are unacceptable when you're trying to control phase-modulated baseband signals. Use an external transmit/receive clock that runs asynchronously to the processor to generate precisely timed conversion-start commands for the A/D converter. (You should also use this same clock for the D/A converter.)

To produce precise start commands, connect a single transmit/receive clock to the filters' $\overline{\text{SYNCIN}}$ terminals. The filters' $\overline{\text{SYNCOUT}}$ signals generate the $\overline{\text{CONVST}}$ and $\overline{\text{LDAC}}$ commands for the converters. You can program one of the eight N^2 $\overline{\text{SYNCOUT}}$ frequencies by using pins DS_0, DS_1, and DS_2. The divider range is 288 kHz/($N^2 \times 5$).

In addition to connecting a transmit/receive clock,

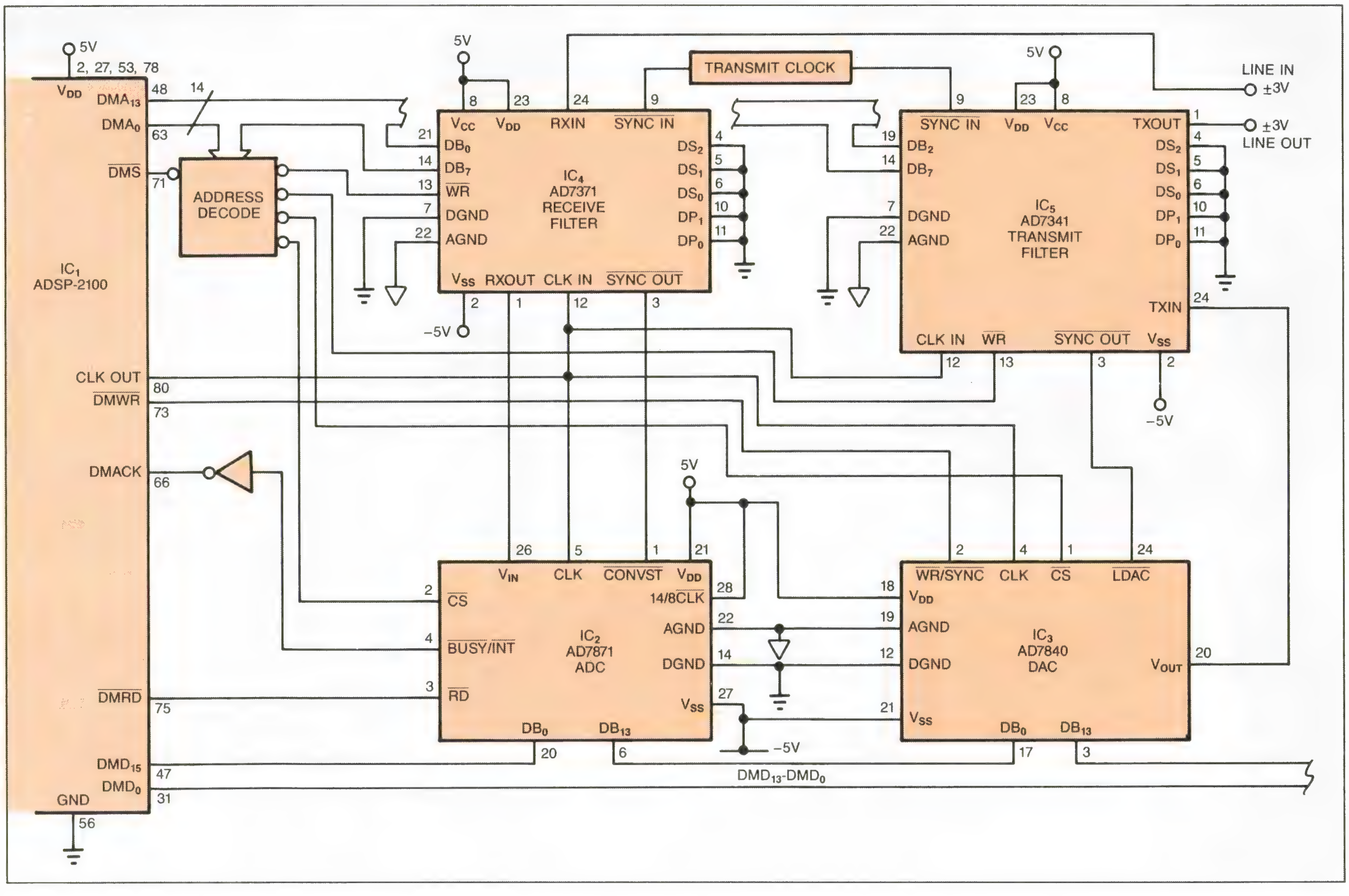


Fig 4—The 14-bit A/D and D/A converters *in this circuit deliver a signal-to-noise ratio of 82 dB for high-speed modem designs.*

If you must extract both amplitude and phase information from analog signals, use a sampling converter with multiple S/H circuits.

you must provide the filters with an input clock signal. You can use clock frequencies of 288 or 576 kHz, or 1.152 MHz; an internal divider generates the proper 288-kHz signal for the circuitry. The logic signals at DP_0 (pin 11) and DP_1 (pin 10) program the correct divider range.

Although the A/D converter's data-access time is 60 nsec and the D/A converter's data-setup time is 20 nsec, you must use wait states to extend the control signals of the 10- and 12.5-MHz ADSP-2100As. (You don't have to add wait states to 6- and 8-MHz processors.) The ADSP-2100 has a DMACK control, pin 66, to support the slow peripheral interface. The processor can read the 14-bit output data as either a single 14-bit parallel word or two 8-bit bytes. The D/A converter accepts a 14-bit, parallel-input data word. (Both the ADC and the DAC also have serial-data-transfer capabilities.)

You don't have to limit the fast sampling converters to high-speed signal-processing applications; their low cost also makes them ideal for control applications. A system's ability to share a single processor, an A/D

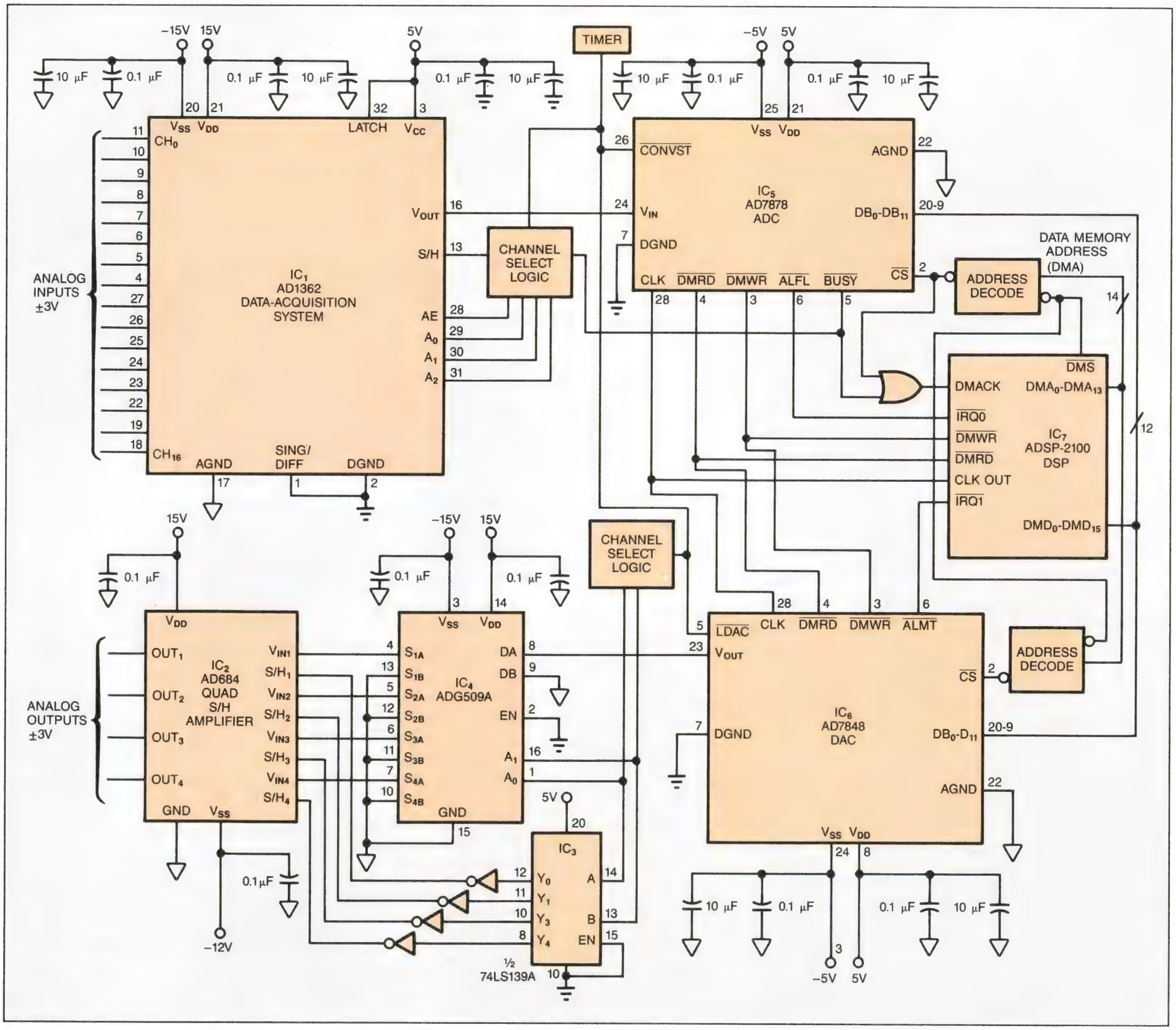


***Fig 5—Internal FIFO buffers** in A/D and D/A converters reduce the interrupt overhead of a DSP.*

converter, and a D/A converter among a number of multiplexed I/O channels further reduces the cost per channel.

In addition to requiring good dc performance, many control applications demand real-time, closed-loop response. For real-time operation, the circuit must compute each output within the sample period. To do so, it must have a fast conversion rate and be able to process input data rapidly. Many high-speed DSPs are capable of handling from eight to 16 channels of real-time data, depending on the complexity of the software.

The multiplexed circuit in **Fig 5** employs an 8- or 16-channel data-acquisition system, two quad S/H amplifers, and 12-bit A/D and D/A converters. The two CMOS converters have many of the same features and specifications as the devices in **Fig 1**, but they also have an 8-word FIFO buffer. The FIFO memory permits the AD7878 to store the results of eight consecutive samples before it needs servicing by the processor. Likewise, the AD7848 D/A converter can update its output eight times before requiring a refill.

You have the option of configuring the circuit for either 16 single-ended inputs or eight differential inputs. A logic high at the AD1362's pin 1 sets an 8-channel, differential input; a logic 0 selects the 16-channel, single-ended operation mode.

The output channel-select logic (not shown in detail) controls the timing of the input and output channel-update rate. Twenty nanoseconds after the channel-select logic chooses the input channel, it should generate a hold command at pin 13. When IC_1's S/H amplifier acquires the signal, IC_5 can grab this signal with its own internal S/H amplifier. The $\overline{\text{CONVST}}$ command for the A/D converter should occur approximately 5 μsec after the circuit selects the input channel. This delay gives the S/H amplifier in IC_1 time to settle. When the AD7878's BUSY output, which is at pin 5, returns high (after the converter's own S/H amplifier has settled), IC_1 can acquire the next signal.

The channel output-select logic simultaneously chooses the proper multiplexer channel for IC_4 and asserts a S/H command at IC_2. The S/H amplifier's acquisition time is 1 μsec. In addition, each channel's low droop rate of 0.001 μV/μsec ensures that the S/H amplifier's accuracy doesn't deteriorate at slow channel-update rates.

To ensure that the D/A converter has sufficient time to settle to ±0.01%, configure the software to strobe the output channel 5 μsec after an $\overline{\text{LDAC}}$ command is given to the AD7848.

The processor must initilize the registers of both the ADC and the DAC when you power up the system. This procedure enables the A/D converter's almost-full output ($\overline{\text{ALFL}}$) and sets the FIFO buffer's effective word length. IC_5 generates an interrupt when the FIFO memory reaches the preprogrammed storage level (from one to eight words). In a similar fashion, when IC_6's FIFO memory is almost empty, it brings its $\overline{\text{ALMT}}$ output high, producing an interrupt.

The internal transfer of data to and from the FIFO occurs in synchronization with the CLK IN signal. The propagation of data through the FIFO is also synchronous to this clock. To avoid read/write conflicts (reading from FIFO location 0 while it's being updated), you must generate the CLK IN signal for both the converters and the host processor from the same source. CLKOUT, CLKOUT2, and CLKOUT are suitable clock sources for the ADSP-2100, the TMS32020, and the TMS32010, respectively.

Consider simultaneous sampling

If your application requires you to extract both amplitude and phase information from analog signals, consider using a sampling converter with multiple S/H circuits. A key parameter for this design is the effective aperture-delay mismatch, which is the difference between the analog (group) and digital (aperture) time delay through the S/H amplifiers.

The circuit in **Fig 6** handles four wideband, strain-gauge signal conditioners for high-speed material testing. Because material analysis is typically performed off line, you can use the circuit in a personal computer's plug-in board. If you install a DMA controller and 64k × 14-bits of memory on the same board, the system can collect as many as 64k-samples of data in the burst mode.

The circuit's A/D converter, IC_2, resembles the device in **Fig 2** except that it has four—instead of one—S/H amplifiers and doesn't have an onboard antialiasing filter. The AD1334 automatically cycles through all four input channels and stores the conversion results in its internal 32 × 14-bit FIFO memory (two bits identify the channel number of the 12-bit data word). For simultaneous sampling, you must tie pin 35, $\overline{\text{SIMULT}}$, to a logic low. You can also sample the channels independently if you tie $\overline{\text{SIMULT}}$ to a logic high.

At the end of each conversion, the AD1334 transfers the conversion results to its internal FIFO memory. Once the FIFO memory has stored 32 samples, the

If you use a converter that has a sampling rate four to eight times the input bandwidth, you can replace a complex filter with a relatively simple design.

onboard controller generates an interrupt, $\overline{IRQ}$. This interrupt initiates a DMA request for the VL82C37A, IC_1. IC_1 acknowledges this request by bringing DACK0 (pin 28) high, thereby producing a chip select for the AD1334. The DMA controller can then execute 32 sequential reads from IC_2. At the end of the transfer, DACK0 returns low. The FIFO-to-memory transfers can occur at the DMA controller's full 8-MHz clock rate if you use high-speed static RAMs. Furthermore, while the DMA transfers occur, the A/D converter continues to sample its input channels.

To ensure that the AD1334 doesn't generate any

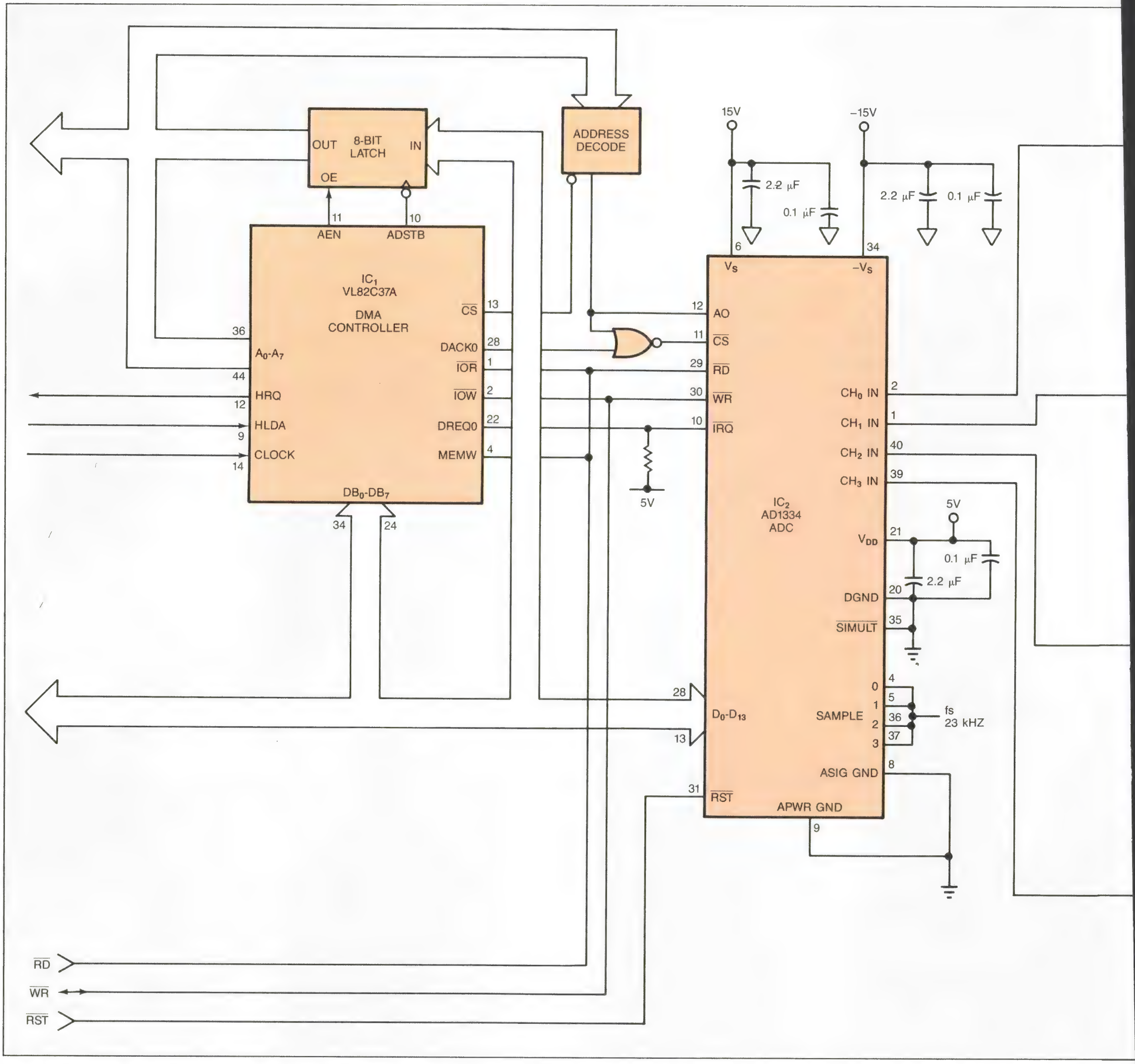
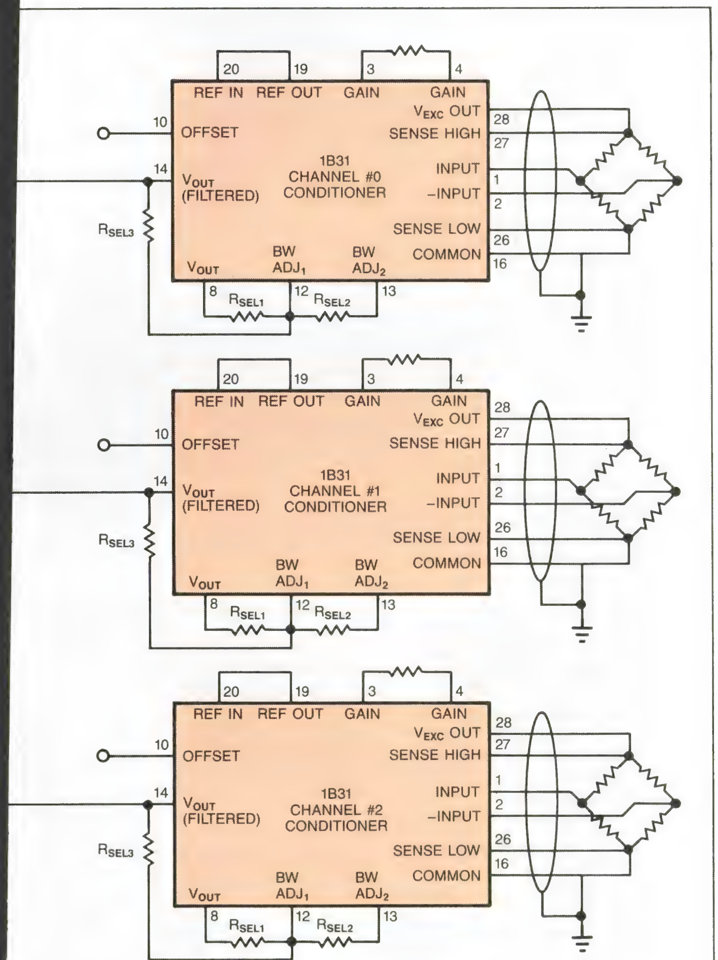


__Fig 6—Using a simultaneous 4-channel S/H amplifier__ within an A/D converter lets you maintain phase coherence among a number of input channels.

false interrupts due to over-range data, you should disable this sampling feature when you initialize the A/D converter. Use IC_1 to load the initialization procedure from memory by using DACK0 to select the converter in conjunction with the $\overline{\text{MEMW}}$ signal.

The IB31 strain-gauge conditioners provide excitation, amplification, and filtering for the strain-gauge bridges. For input bandwidths from 2 to 20 kHz, you must program the two-pole-filter cutoff frequency with three external resistors (R_{SEL1}, R_{SEL2}, and R_{SEL3}), using the equations:



$$R_{SEL1} = \frac{20\ \text{k}\Omega}{\left(\frac{f_c}{1\ \text{kHz}}\right) - 1}$$

$$R_{SEL2} = \frac{16\ \text{k}\Omega}{\left(\frac{f_c}{1\ \text{kHz}}\right) - 1}$$

$$R_{SEL3} = \frac{40\ \text{k}\Omega}{\left(\frac{f_c}{1\ \text{kHz}}\right) - 1}$$

Because the maximum simultaneous sample rate is 28 kHz, you should restrict the input bandwidth to less than 14 kHz to satisfy the Nyquist criteria. The circuit might require some additional filtering if the input bandwidth is close to the Nyquist frequency.

To set the gain of a conditioner's internal instrumentation amplifier, install a resistor between pins 3 and 4 on each device. The conditioner's output should range from ±5V to match the A/D converter's input range. You can determine the gain with the equation: $G = 2 + (80\ \text{k}\Omega/R_G)$. For R_G, you should use a resistor that has a low temperature coefficient (5 ppm/°C). You can also add a 50Ω potentiometer in series with R_G to provide fine span adjustment.

In many applications you may want to calibrate the system. To do so, you can either rely on manual calibration techniques or add autocalibration to your design. One autocalibration method is to have the system switch out the strain gauge and switch in a shunt calibration resistor. The shunt resistor should produce a signal that is 80% of full scale. Your software can compensate for any offset. Another approach is to use a quad D/A converter and a quad op amp for a bipolar offset trim of the conditioner's output-offset adjustment at pin 10.

To protect the equipment from 115V line shorts, you can install back-to-back diodes (FDH333, IN963) between pin 1 and ground, and pin 2 and ground on each conditioner. Connect a 15-kΩ, 1W resistor in series with both of these inputs. In addition, you must use two back-to-back diodes (IN963) between pin 26 and ground, and pin 27 and ground.

You can use high-resolution sampling converters in high-speed modems.

The newest A/D converters perform well not only when coupled with fast signal processors, but also when connected to slower microprocessors. Besides reducing the number of ICs required in a design, the ADCs' high conversion rates improve the system's bandwidth. For example, you can use a fast sampling converter connected to a personal computer to capture wide-bandwidth analog signals.

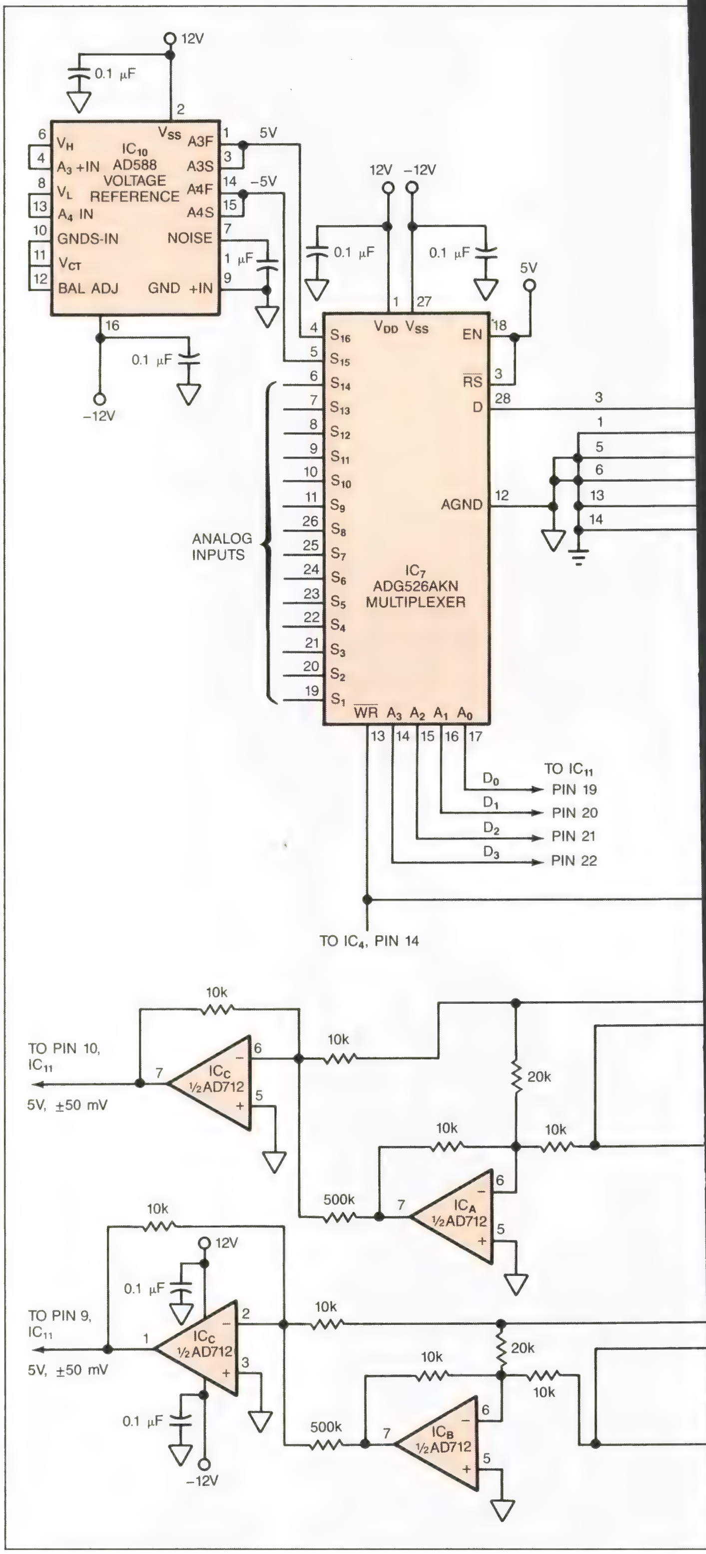
The 12-bit AD678 in **Fig 7**, for example, handles sample rates to 200 kHz and input bandwidths to 500 kHz. Because the S/H amplifier, the reference, the clock, and the digital-output registers are integrated on this A/D converter, you need few ICs. You can even upgrade the system to 14-bit resolution by plugging in the AD679—a pin-compatible, 14-bit version of the AD678.

You can use one of two I/O port decoding methods: fixed or variable. Fixed I/O port decoding maps the data-acquisition system (DAS) into a fixed address space. If you take this approach, you can use inexpensive gates and buffers. However, the hardware restricts the address location, creating possible address conflicts between boards located in the PC's four other expansion-card slots. You can try to use a variable decode scheme to overcome these address conflicts: Position the DAS in an available address block (512 bytes) by changing the positions of switch SW_1. The 74LS688, which is an 8-bit identity comparator, matches the address on the PC bus with the address that the switch selects. Bits A_0 through A_8 define the 512 port addresses. When inactive, bit A_9 enables data transfers from the system board; it also enables data transfers from the five other expansion-card slots.

During a DMA read/write signal, the AEN pin is active high. You can use this signal to avoid incorrect port addressing during a DMA. When IC_1's P and Q inputs are equal, pin 19 goes low, thereby enabling the octal bus transceiver, IC_2's 3-state outputs and decoders, IC_3, and IC_4. The $\overline{IOW}$ and $\overline{IOR}$ signals control the direction of the data. The circuit decodes as many as eight read and write locations.

Multichannel data-acquisition systems must be able to accept a wide variety of input signals of varying full-scale amplitudes. To let the PC (under program control) select the desired channel during an I/O write cycle, connect the multiplexer to the data bus on the DAS. You can use two of IC_7's 16 input channels for the plus and minus full-scale input voltages during the calibration cycle.

You should design the system to perform low-level



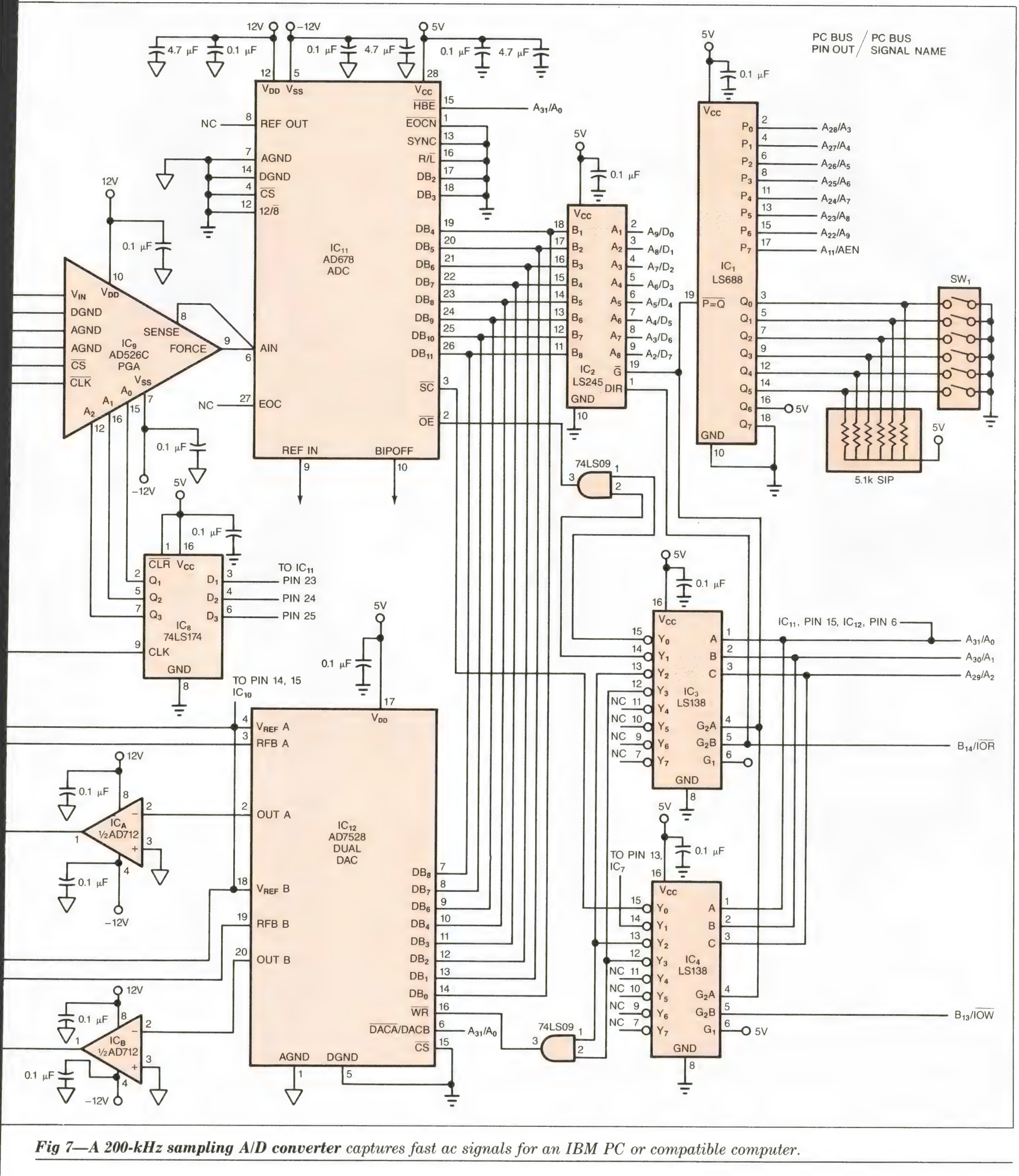


*Fig 7—**A 200-kHz sampling A/D converter** captures fast ac signals for an IBM PC or compatible computer.*

If you want to calibrate the system, you can rely on manual calibration techniques or add autocalibration to your design.

signal conditioning and amplification that is external to the PC's chassis. A number of signal conditioners are available for this function. Once amplified, the input signal can enter the PC's chassis, where a digitally programmable gain amplifier scales each channel's signal to the ADC's full-scale range.

The PGA, IC_9, increases the resolution of the A/D converter's LSB by increasing the input-signal range. For example, if the full-scale input range is 500 mV, the LSB is equivalent to 122 μV. Such a low signal level requires that the noise levels on the DAS signal and the ground paths be less than 122 μV. These noise levels are impossible to achieve inside a noisy PC chassis. However, if you set an amplifier for a gain of 16, it can scale the same 500-mV full-scale signal to 8V, which corresponds to an LSB weight of 1.95 mV.

You can program the SPGA for gains of 1, 2, 4, 8, and 16. To minimize digital feedthrough from the data bus at pins 12, 15, and 16, configure the AD526C in the transparent mode and latch the data with an external D-type flip-flop. You can also increase the available gain range of the DAS by cascading two AD526s. Furthermore, to preserve the signal accuracy at the A/D converter's input by minimizing IR drops, IC_9 has optional force and sense connections. You must tie the force and the sense to the A/D converter's analog input.

Correct errors during the calibration cycle

When you consider using an amplifier for your DAS, remember that you have to accept the device's nonlinearity, poor settling time, and insufficient bandwidth. You can, however, correct errors induced by offset voltage, gain error, and bias curents during a calibration cycle.

Autocalibration eliminates the need for time-consuming and expensive manual calibration techniques. To add autocalibration to your system, replace the typical bipolar offset and gain potentiometers with a dual 8-bit D/A converter (IC_{12}) and output-scaling op amps (A_1, A_2, and A_3). Address line A_0 connects the

$\overline{DACA}$/DACB control line to the PC bus. Address location 0302H loads data into DACA, and address 0303H selects DACB. You can use an AD588 precision voltage reference that is configured in the ±5V mode to generate the calibration voltages for the DAS. If you install a 1-μF capacitor between pins 7 and 9 of the reference, you reduce the device's broadband output noise to approximately 200 μV.

The gain error is the worst-case deviation from the nominal 5V for which the circuit must correct. To trim the gain error, the two autocalibration circuits provide 5V ±50 mV to both the REFIN (pin 9) and the BIPOFF (pin 10) on the AD678. The two circuits' resolution is 100 mV/256 or 390 μV, which represents 0.16 LSB for the AD678.

The calibration routine should select the −5V reference channel and program a gain of 1 for the SPGA. The program should continually decrement the output of DACA until the program detects the minus full-scale transition in the AD678. In addition, the software can determine the average code width that the AD678 can accept, divide the code width by 2, and place the BIPOFF in the center of the first code, rather than at the transition from the first to the second code. The gain calibration should follow a similar procedure.

You can extend the calibration cycle to all gain ranges, assuming that the plus and minus full-scale voltage sources are available at the input to the multiplexer. To extend the cycle, configure the calibration routine to store the bipolar offset and gain factors for each gain range in memory. When the program alters the gain range, it can retrieve the calibration factors and load them into IC_{12}.

The A/D converter has a selectable 12- or 8-bit interface. To set the 8-bit mode, simply ground the 12/8 pin, as shown in **Fig 7**, and memory-map the AD678 into two read-address locations: 0300H for the low-byte data and 0301H for the high-byte data. When $\overline{HBE}$ is low and $\overline{OE}$ is driven low, the host CPU accesses high-byte data. When $\overline{HBE}$ is high and $\overline{OE}$ is driven low,

Don't limit the use of fast sampling converters to high-speed DSP applications; their low cost also makes them ideal for control applications.

the CPU reads low-byte data. If you leave $\overline{OE}$ high, the AD678 data bus is forced into a high-impedance state, allowing other devices on the DAS to communicate with the host.

To maintain system accuracy in a PC's harsh environment, you need to employ power-supply decoupling and grounding carefully. You should use a 0.1-µF ceramic capacitor at all analog and digital power pins to eliminate high-frequency noise. Add a 4.7-µF tantalum capacitor in parallel with the 0.1-µF capacitor at the AD678 power supplies to decouple a broad range of frequencies. In addition, you can install 33-µF capacitors at multiple locations on the 5V supply so that the system can deal with large, slow power fluctuations.

To minimize ground inductance, use separate analog and digital ground planes. If a ground plane isn't available, you can use a single-point ground or a "star" ground. A "star" ground reduces analog and digital ground-current loops. You must make sure that the single connection between the two grounds is as close as possible to the A/D converter. Furthermore, you should reference the grounds of all DAS analog input signals to the AD678's analog/digital ground connection.

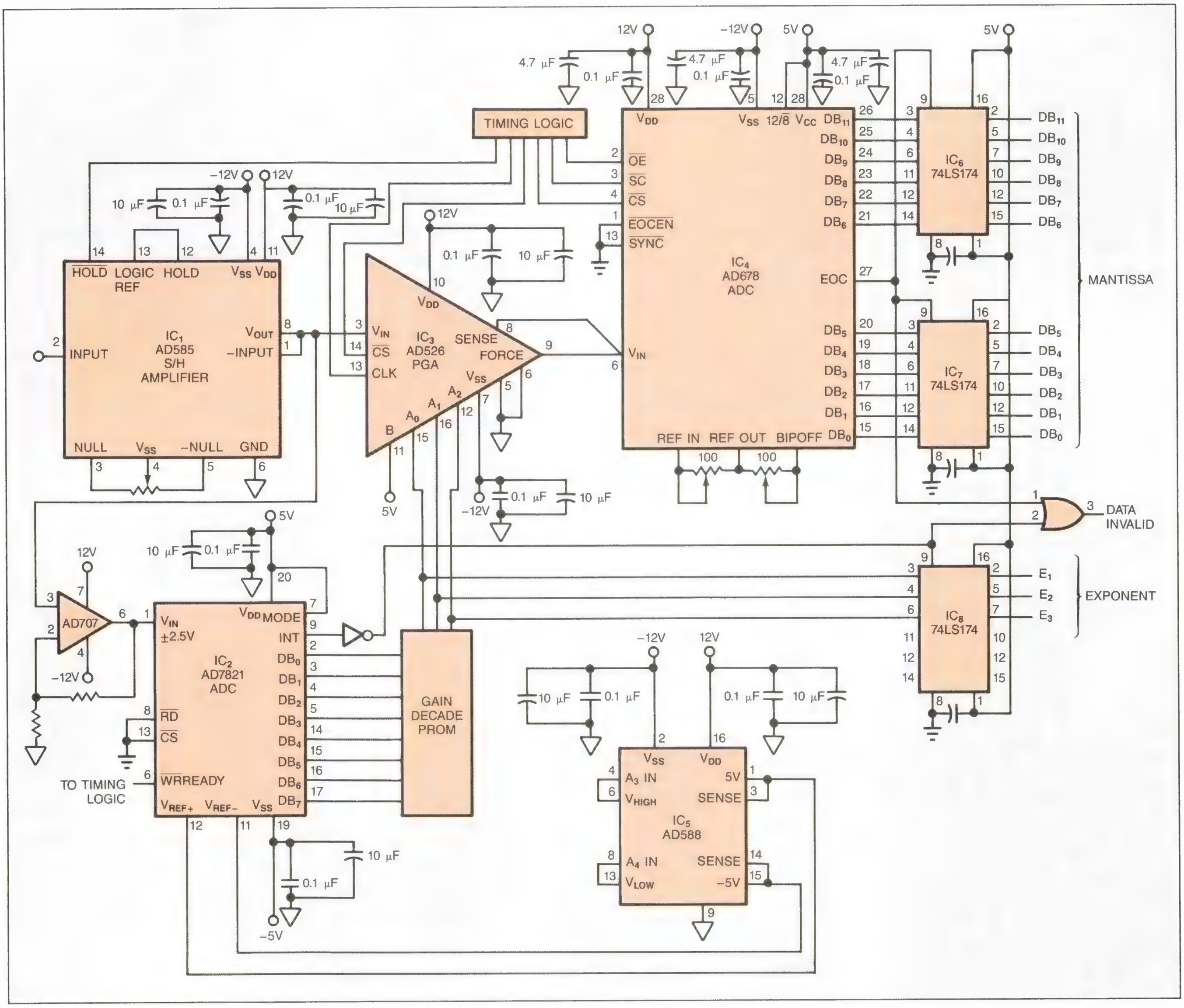


***Fig 8—A floating-point A/D converter** extends the dynamic range of a 12-bit A/D converter to 16 bits.*

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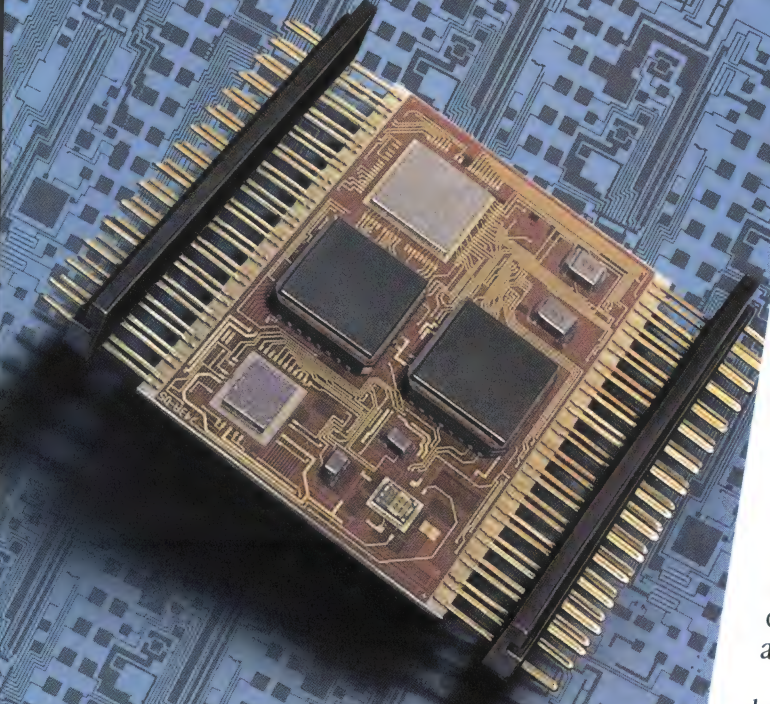

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Instead of using an expensive high-resolution ADC, you can use a floating-point design to extend the dynamic range of a 12-bit sampling ADC.

Many analog waveforms have a wide dynamic range. Instead of using an expensive high-resolution ADC, you can use a floating-point design (**Fig 8**) to extend the dynamic range of a 12-bit sampling ADC. If you design the configuration properly, you can extend the circuit's dynamic range to 16 bits.

A floating-point design has two components of the A/D conversion process: a mantissa and an exponent. **Fig** 8's design derives the exponent from the flash A/D converter, IC_2, and then uses the exponent to set the gain for the second higher-resolution converter, IC_4. The output from this second converter is the mantissa.

The floating-point circuit in this design maintains a 100-kHz throughput. The sampling ADC's onboard S/H amplifier improves the throughput by means of pipelining techniques. Because a floating-point design requires a 2-step approach, the external S/H amplifier can acquire and convert one input sample while the high-resolution A/D converter digitizes the previous sample. The principle delays in the circuit are the S/H amplifier's (IC_1) 3-μsec acquisition time and the PGA's (IC_3) 3.5-μsec settling time. As soon as IC_1 settles to $\pm 0.01\%$, the 8-bit AD7821 converts the sampled signal. This process takes 660 nsec. A PROM lookup table then translates the 8-bit digital output word to a 3-bit digital gain setting for the SPGA. The sampling ADC (IC_4) then samples and converts the SPGA's output.

The AD7821 latches the 3-bits of gain data into the exponent latch, IC_8, with its $\overline{\text{INT}}$ control signal. You may have to extend the length of this signal, depending on the propagation delay of the PROM. In a similar fashion, IC_4 latches its 12-bit output data into the mantissa latches, IC_6 and IC_7, with its end-of-convert control signal, EOC. Because the entire circuit works asynchronously to the processor, you need a data-invalid signal to prevent reads from the latches during data updates. This invalid signal is generated by an OR gate for the $\overline{\text{INT}}$ and EOC signals.

The ac performance of the floating-point ADC depends on how continuous the transfer function is among the AD526, the AD7821, and the AD678. You can improve the performance by trimming the reference voltage of the two A/D converters.

The magnitude of the input signal also has an impact on the dynamic performance. With a full-scale input (the SPGA is set for a gain of 1), the system's quantization error limits the noise floor. With a small-scale input signal, the SNR floor is lower because the AD678's LSB is small. The harmonics are -100 dB from the fundamental input frequency.

The dc performance of the floating-point design depends on the sophistication of the trim scheme you use. As in the case of the PC interface board, you can use an autocalibration design to reduce the differential nonlinearity of the different gain settings of the AD526.

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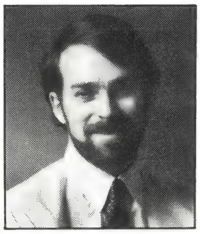
Authors' biographies



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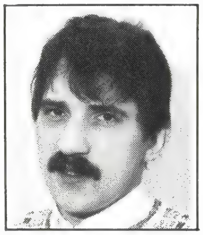

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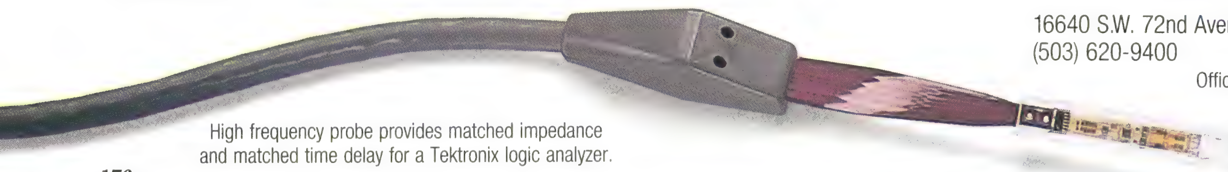

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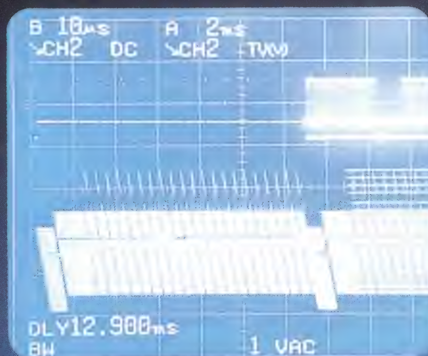

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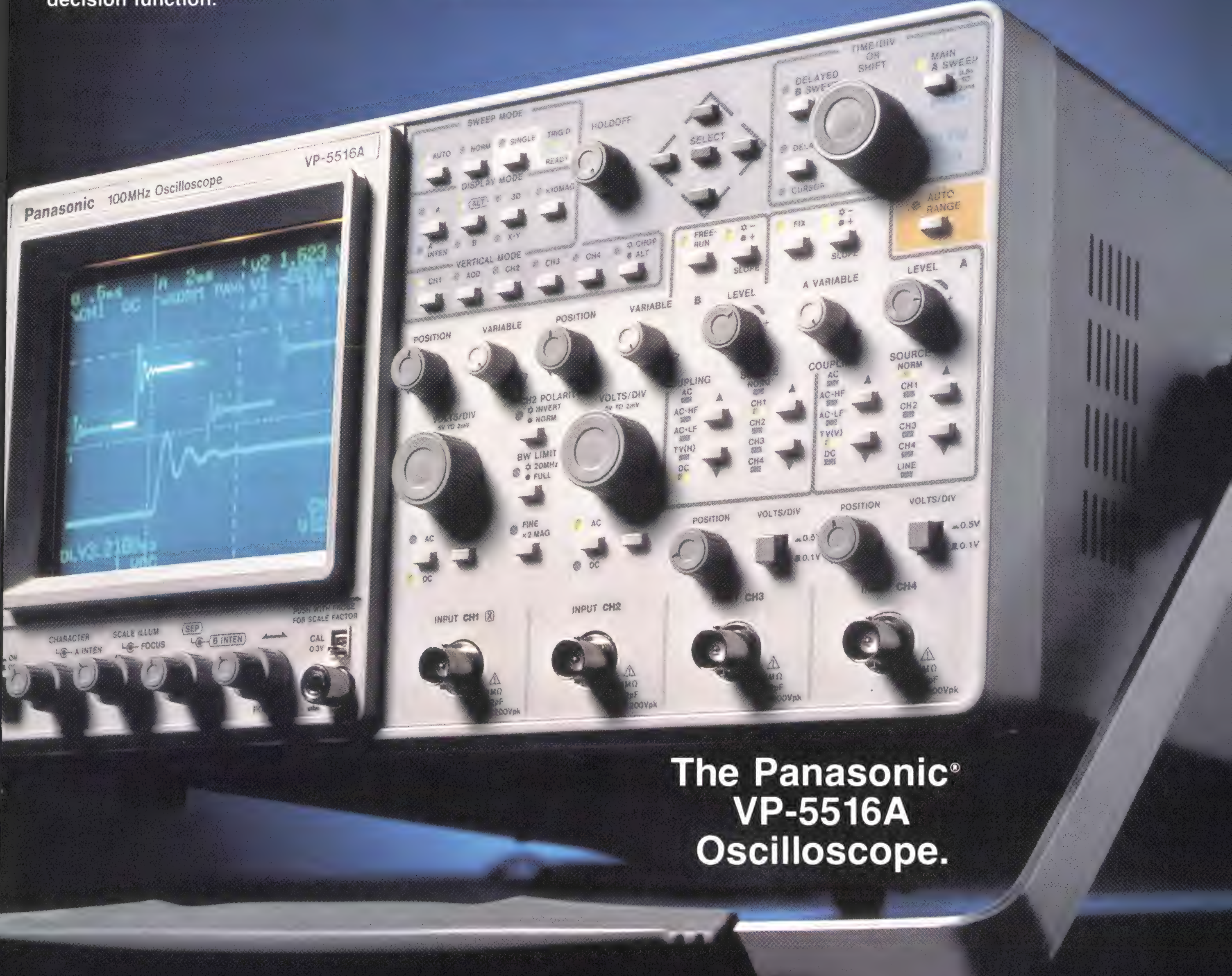

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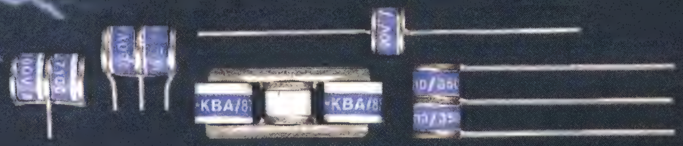

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CIRCLE NO 124

DESIGNER'S GUIDE

dynamic RAMs
Part 4

Attention to layout details facilitates DRAM-board design

Once you've completed the paper-design stages of developing a DRAM system, you must transfer the design from paper to working hardware. This article, part 4 of a 4-part series, offers some board-layout tips that can ease the transition. The first three parts of this series concentrated on choosing DRAMs, tailoring your memory-system architecture for them, and designing a DRAM controller.

Fred Tabaian and Marlene M Toomer,
Texas Instruments

Before committing your dynamic-RAM (DRAM) system design to hardware, consider some of the real-world problems you may face in DRAM-board layout. Some of these considerations include capacitive loading, trace capacitance, transmission-line effects, terminations, and board-layout problems. Anticipating the possible pitfalls and taking steps to overcome them can make your DRAM-board-layout task relatively easy.

When you design high-speed, high-bit-density systems, you must be aware of capacitive-loading effects. The input impedance of a DRAM is predominantly capacitive. Typical capacitance values range from 4 to 7 pF for data and address lines and 8 to 10 pF for control lines. The loading effect caused by DRAM input capacitance can be significant for memory systems that contain many DRAMs. For example, consider a 4M-word memory system whose system architecture consists of four banks of 1M-bit DRAMs. Because each bank contains 16 DRAMs, a total of 64 DRAMs is attached to each address line. Therefore, the input capacitance in that system amounts to 64×7 pF = 448 pF/line.

A control line, such as the $\overline{\text{WRITE}}$ signal, must drive an even higher capacitive load—as much as 640 pF. The loading problem is even worse when the system contains memory units that store parity bits for error detection and correction. These capacitive loads significantly exceed the typical 15- to 50-pF test loads that manufacturers use when specifying IC timing parameters. In order to maintain fast rise and fall times, the drivers must have large output currents to drive these large capacitive loads. Although high-bit-density DRAMs such as 16M-bit DRAMs offer some temporary relief, the insatiable demand for more capacity with

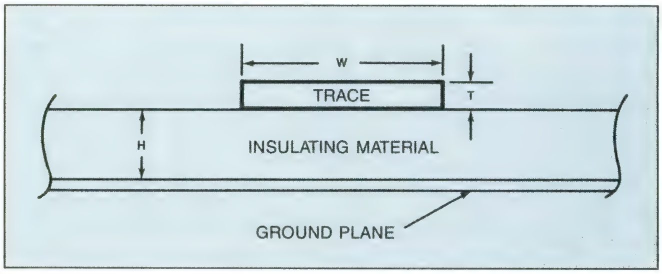

Fig 1—A microstrip consists of a printed trace *that is isolated from a ground plane by a layer of insulating material. The trace's width (w), thickness (t), and height above the ground plane (h) determine its electrical characteristics.*

The loading effect caused by DRAM input capacitance can be significant for memory systems containing many DRAMs.

faster access times will keep the memory designer employed.

Another factor that contributes to capacitive loading is the pc board's trace capacitance. Most high-performance memory pc boards use microstrip lines to interconnect system components. A microstrip is essentially a printed trace that's separated from a solid ground plane by a layer of insulating material (**Fig 1**). Because a microstrip line is a partially shielded transmission line, many of the concepts and equations applicable to transmission lines apply to microstrips.

A transmission line can be modeled as a lumped network of inductors and capacitors with a constant inductance and capacitance per unit length. For simplicity's sake, the resistance per unit length is considered negligible and can be ignored. The narrower the trace of the microstrip line, the higher the inductance and the lower the capacitance per unit length. The lumped model shown in **Fig 2** includes the input capacitance of a number of DRAMs, which the model assumes are evenly distributed along the microstrip. The model ignores the DRAMs' lead inductance and resistance.

The characteristic impedance of the transmission line is:

$$Z_0 = \sqrt{L/C},$$

where L and C are the lumped inductance and capacitance values for the transmission line, which are determined by the microstrip geometry. Under the assumption that the trace is relatively thin and the ground plane is large compared with trace's width, the characteristic impedance of the transmission line is:

$$Z_0 = \frac{87}{\sqrt{E_r + 1.41}} \ln\left[\frac{5.98h}{0.8w + t}\right]$$

where t is the trace thickness, w is the trace width, and h is the trace height above the ground plane. All dimensions are in thousandths of an inch. E_r is the dielectric constant for the pc-board material.

A pulse propagates along a microstrip line at

$$t_p = 0.0848\sqrt{0.475E_r + 0.67} \text{ nsec/in.},$$

and the trace capacitance is

$$C_0 = 1000\,(tp/Z_0) \text{ pF/in.}$$

All of these equations apply for dielectric constants ranging from 1 to 15 and trace width-to-height ratios ranging from 0.1 to 3. For example, a pc board with 10-mil-wide and 2-mil-thick traces operating over 10-mil-thick G10 glass-epoxy medium ($E_r = 5$) has the following characteristics:

- $Z_0 = 61\Omega$
- $t_p = 0.15$ nsec/in.
- $C_0 = 2.5$ pF/in.

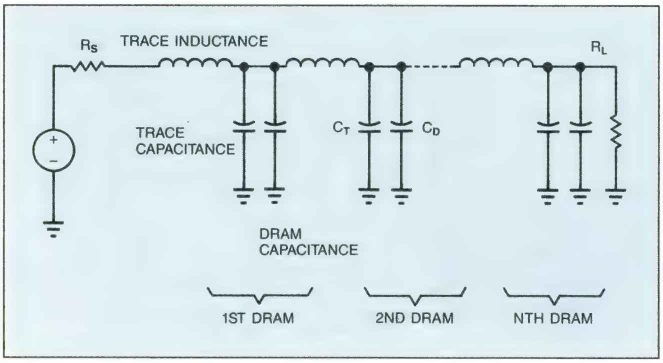

***Fig 2—The lumped model for a microstrip** loaded with multiple DRAMs consists of the trace's inductance and capacitance as well as the input capacitance of each DRAM.*

These characteristics apply only to a microstrip line with no loading, however. In order to determine the characteristics of a functional memory board, you must account for the distributed input capacitance for the DRAMs and other ICs on the microstrip line. Assuming that the DRAMs are evenly distributed along the microstrip, the modified characteristic impedance is:

$$Z_0' = \frac{Z_0}{\sqrt{1 + \frac{C_d}{C_0}}},$$

and the modified propagation time is:

$$tp' = tp\sqrt{1 + \frac{C_d}{C_0}} \text{ nsec/in.},$$

where C_d is the distributed DRAM input capacitance per inch. Assuming a microstrip line's DRAMs are 0.5 in. apart, the worst-case distributed input capacitance for an address line is

$$C_d = 7 \text{ pF}/0.5 \text{ in.} = 14 \text{ pF/in.}$$

When you use this value, the pc board's modified char-

acteristics are

$$Z_O' = 23.5\Omega$$
$$t_p' = 0.38 \text{ nsec/in.}$$

When a pulse propagates along a transmission line, a change in the line's characteristic impedance, such as an unterminated load, causes a reflection to occur. The load's reflection coefficient determines how much of the transmitted pulse reflects back to the source. The load's reflection coefficient is:

$$P_L = \frac{R_L - Z_0}{R_L + Z_0},$$

where R_L is the load's terminating impedance. If R_L is larger than Z_O, the load reflects a positive pulse to the source. The load reflects a negative pulse when R_L is smaller than Z_O.

A similar effect occurs if the reflected pulse encounters discontinuity of the transmission-line impedance caused by the source impedance. The source's reflection coefficient determines how much of the reflected pulse is retransmitted towards the load. The source's reflection coefficient is

$$P_S = \frac{R_S - Z_0}{R_L + Z_0},$$

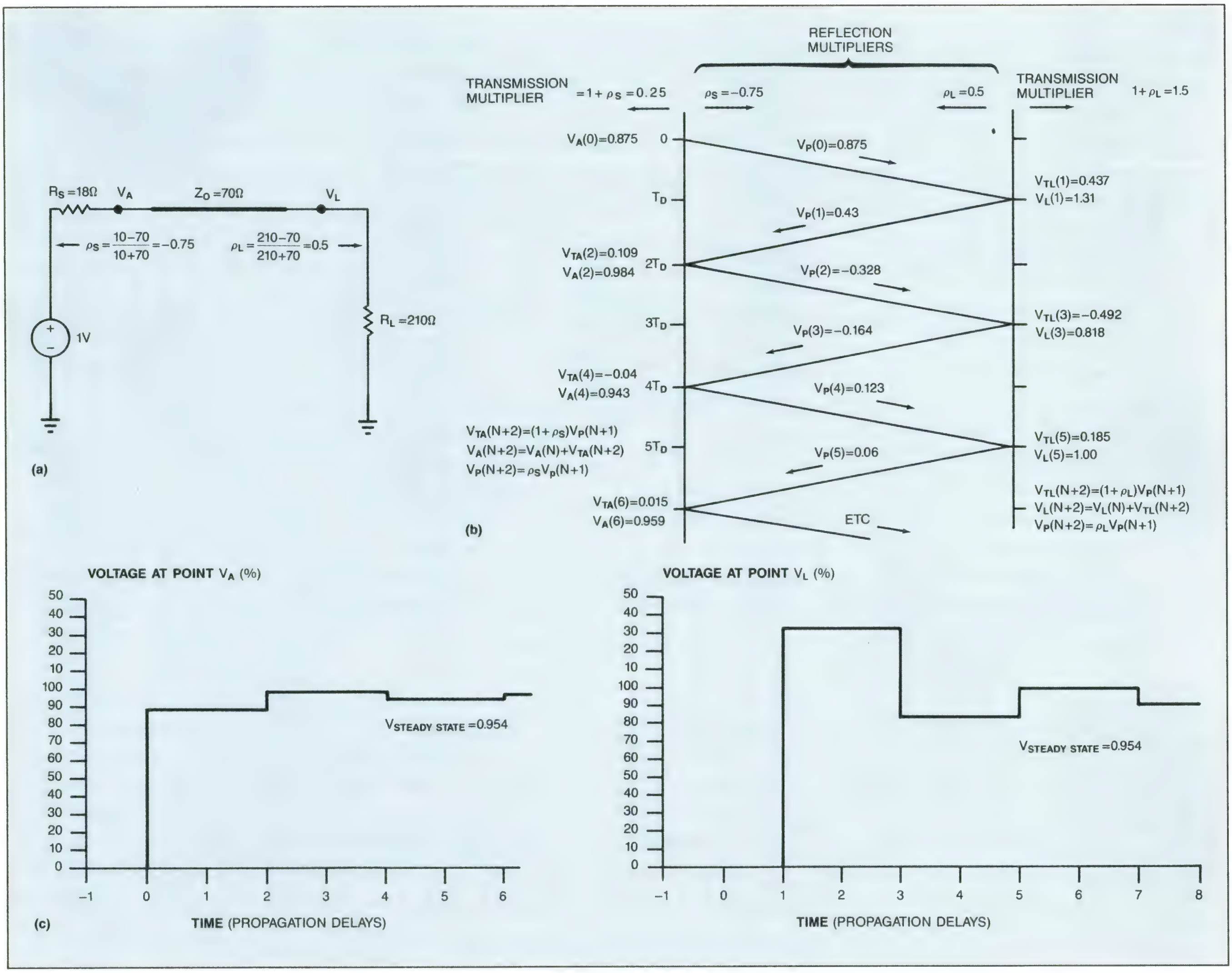

__Fig 3—Terminating a 70Ω microstrip with a 200Ω load__ and driving it with a 1V step from a 10Ω source __(a)__ produces the ping-pong effect shown in the lattice diagram __(b)__.

Most high-performance memory pc boards use microstrip lines to interconnect system components.

where R_S is the source impedance. Because the source impedance of a buffer driver is usually smaller than the line's characteristic impedance, the retransmitted pulse is generally negative.

A lattice diagram provides a visual representation of the ping-pong effect that a transmission line exhibits when the source and the load impedance differ from the line's characteristic impedance. When a pulse reaches the end of the line, the reflection and transmission multipliers (ρ and $1+\rho$) determine the reflected and transmitted voltages, respectively. Therefore, the composite voltage at each end of the line consists of the sum of the transmitted voltages each time it receives another reflection. For example, applying a 1V step to the transmission line shown in **Fig 3a** results in the lattice diagram shown in **Fig 3b**. The reflection and transmission multipliers at the source are -0.75 and 0.25, respectively. Similarly, the reflection and transmission multipliers at the load are 0.5 and 1.5, respectively.

The voltage divider between R_S and Z_O causes the initial transmitted pulse amplitude to equal

$$V_P(0) = 1.0V \times 70\Omega/(10+70)\ \Omega = 0.875V.$$

After a delay established by the length of the transmission line T_D, the pulse arrives at the load. At this time, the load reflects a $0.5 \times .875 = 0.437V$ pulse back toward the source while the load absorbs $1.5 \times 0.875 = 1.31V$. When the reflected pulse reaches the source (another T_D time delay later), a $-0.75 \times .437 = -0.328V$ pulse reflects back toward the load while the source voltage increases from 0.875V to $0.875 + 0.25 \times 0.437 = 0.984V$. This ping-pong effect continues until the reflections decay exponentially. Eventually, the line settles to a steady-state voltage of $V_{SS} = V_L = 1.0V \times 210/(210+10) = .954V$. The voltage waveforms for both ends of the line are shown in **Fig 3c**.

Multiple reflections, which appear as ringing on the line, can seriously degrade a system's performance. If the ringing is large enough, a single timing pulse may trigger an edge-sensitive device more than once. Excessive ringing also slows down the system, because the circuitry must wait for the line to settle before reliably decoding a logic state. In some cases, severe ringing can be catastrophic. If the line voltage swings as much as 1 to 2V below ground, a DRAM's contents can be altered or a driver may be physically damaged.

The method for minimizing reflections is to terminate the transmission line with its characteristic impedance. If the load impedance (R_L) and the source impedance (R_S) equal the line impedance (Z_O), both the load-reflection and the source-reflection coefficients (ρ_L and ρ_S) are equal to zero. Essentially, there are two termination methods for reducing reflections—series termination and parallel termination.

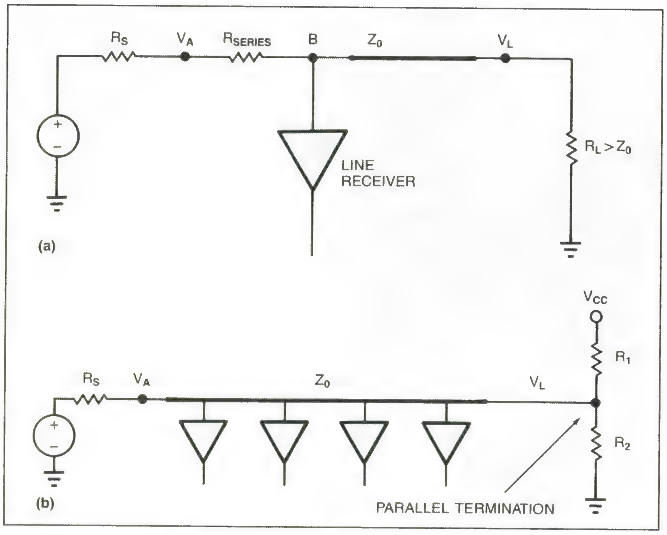

***Fig 4—There are two ways to terminate a transmission line** to reduce reflections. The series-termination method **(a)** matches the source's impedance to the line's characteristic impedance; the parallel method **(b)** matches the end of the transmission line to the line's impedance.*

You employ series termination by inserting a resistor between the source and the microstrip trace **(Fig 4a)**. To make the source-reflection coefficient zero, choose the resistor value such that $R_S + R_{series} = Z_O$. Because the series resistor increases the signal rise and fall times (thereby slowing the system), in practice you should use a small enough resistor to reduce the ringing to an acceptable limit.

A disadvantage of the series-termination method is that distributed loads along the transmission line must wait for the reflected pulse from the unterminated end of the line before receiving the full transmitted voltage. For example, the input voltage to the line receiver shown in **Fig 4a** is only half of the source voltage until the series termination absorbs the reflected pulse from the far end of the transmission line. Therefore, the series-termination method is most effective when all of the loads are lumped together at the end of the line.

The parallel-termination method is shown in **Fig 4b**. You terminate the end of the transmission line by making the parallel equivalent of resistors R_1 and R_2 equal

to Z_0. By setting $R_2 = 1.5 \times R_1$, the termination guarantees a logical-high voltage level without the need for excessive drive current.

Parallel termination is inherently faster than series termination for long transmission lines, because a series resistor doesn't slow down the signal's rise and fall times. In addition, distributed loads receive the fully transmitted signal as the pulse propagates along the line. This situation occurs because the source resistance is usually smaller than the line impedance; thus, the amplitude of the transmitted pulse is nearly equal to the source voltage. The termination absorbs the transmitted pulse when it reaches the end of the line.

Looks can be deceiving

At first glance, it might appear that parallel termination is the better method for mimimizing reflections in a DRAM system. However, when you consider power dissipation, component count, and switching speed, you'll come to a different conclusion. Take power dissipation, for example. In a CMOS design, a series termination consumes power only during the signal-level transition time, and it draws only a trickle of supply current while in a quiescent state. If you use parallel termination, on the other hand, the supply-current drain when the system is in the quiescent state can be appreciable. Because the resistors provide a low-impedance path (typically less than 300Ω) between the power supply and ground, using parallel terminations on all of the microstrip lines on a pc board can create a board hot enough to toast marshmallows.

Then consider the number of parts required to implement the termination. The parallel-termination method requires one more part than the series-termination method does. True, you can obtain dual-resistor packs that occupy the same amount of board space as single-resistor packs do. However, if you use discrete termination resistors mounted on the board, the components will take up more board space.

And consider the switching speed. The lattice-diagram analysis for pulse reflections on a line ignores the effect of the pulse's rise and fall time. You can make a microstrip line short enough, however, that the reflected pulse from the end of the line returns to the source before the transmitted pulse changes state. If the line has a series termination at the source, the reflection is absorbed during the signal-transition period. Therefore, all of the distributed loads experience nearly the same voltage transients. As a rule of thumb, you should make the microstrip lines short enough that the signal's rise or fall time is at least twice the total propagation delay of the microstrip line.

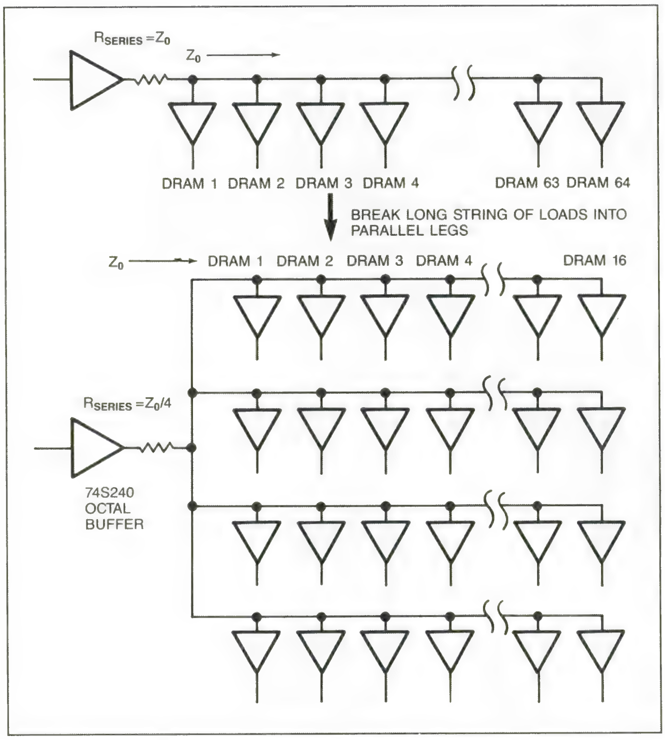

***Fig 5—Instead of driving a large number of DRAMs** with a single microstrip line, you should distribute the DRAMs along a number of parallel paths.*

This condition is not as difficult to achieve as it might sound. **Fig 5** shows how a microstrip line with 64 distributed DRAMs can be arranged as four parallel lines with 16 DRAMs each. Assuming that a pulse propagates along the capacitively loaded line at 0.38 nsec/in. and that the DRAMs are spaced every 0.5 in., the total propagation delay for one of the four parallel legs is

$$16 \text{ DRAMs} \times 0.5\text{-in/DRAM} \times 0.38 \text{ nsec/in.} = 3 \text{ nsec.}$$

A 74S240 octal buffer has a rise time on the order of 8 to 12 nsec when driving a moderate capacitive load, such as the input capacitance for 16 DRAMs (16×7 pF $= 112$ pF total). The series-termination resistor increases the rise time even further so that the condition for the above rule of thumb is easily met. Using a series resistor that produces a reflection coefficient ranging from 0.1 to 0.2 keeps the reflection transient less than 1% of the full transmitted voltage. Essentially, every DRAM on the microstrip line receives the same voltage waveform.

Multiple reflections, which appear as ringing on the line, can seriously degrade a system's performance.

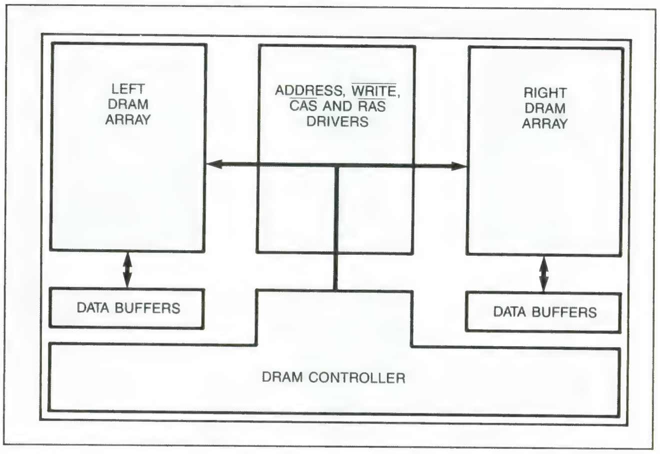

***Fig 6—A board layout that places the drivers** for the address, $\overline{WRITE}$, $\overline{CAS}$, and $\overline{RAS}$ in the center of the board minimizes the lengths of the traces to the DRAM arrays.*

Because the four transmission lines are in parallel, the series-termination resistor should be set to $Z_0'/4$. For the Z_0' given in equation 11, the series resistor should be set to approximately 6Ω. In fact, you may not require an external termination resistor at all, because the output impedance of the driver is close to the calculated termination value. Eliminating the external resistor reduces the number of parts, making the pc board both less expensive and more reliable.

A caution light for line drivers

Because the output-drive capability of most VLSI DRAM controllers is only a few milliamps, you must use line drivers to drive large DRAM arrays. Such a situation can strain the line drivers. In systems that use octal buffers as line drivers (as many do), for example, the buffers come under a lot of strain when all eight outputs must sink large currents simultaneously. This fact leads to a second rule of thumb for memory-system design: When using an octal buffer as a line driver, no more than four of the outputs should switch simultaneously. Obviously, this requirement will make it harder for you to design the system to handle sequential addressing. However, adhering to the requirement will enhance the system's reliability.

In addition, when estimating the system's speed you must account for a signal's propagation delay through the buffer. A fast buffer may exhibit a propagation delay from 3 to 7 nsec when driving capacitive loads as large as 50 pF. Unfortunately, IC manufacturers specify a buffer's switching speed with only a 50-pF load or less, which is not a representative load for driving multiple DRAMs. For large capacitive loads, a DRAM system's propagation delay may be as large as 15 nsec. The astute designer must determine the delays incurred under actual conditions before estimating the system's speed.

A layout philosophy provides the framework

How you arrange the signal traces and components on the pc board has a great impact on the memory system's performance. You should keep the signal traces as short as possible to minimize propagation delays. **Fig 6** shows an effective layout that conserves the trace lengths. By placing the drivers for the memory address, $\overline{\text{WRITE}}$, $\overline{\text{RAS}}$, and $\overline{\text{CAS}}$ line in the center of the pc board, you can minimize the average length of the microstrip lines emanating from these drivers to each memory array. Another benefit of this approach is that you can place the microstrip lines from the data buffers perpendicular to the control and address lines, a scheme that minimizes crosstalk.

When employing series termination, you should place the resistor as close as possible to the driver output. Essentially, you should avoid placing a long trace between the driver and the resistor, because a long trace will increase the propagation delay and cause additional reflections. A long trace will reduce some of the advantages of the series-terminated line.

Besides considering the signal traces, you must pay attention to power distribution throughout the pc board. A high-speed DRAM system has a large number of simultaneous state changes, which tax the power-supply current. The instantaneous supply-current demand can exceed 1A. Of course, you should place a bypass capacitor directly on each DRAM's power pin. There are a variety of capacitor types that function well as bypass capacitors. DRAM and capacitor manufacturers have performed extensive testing of these components and offer many practical tips on their use in application notes.

Guidelines for laying out DRAM boards

As in any discipline, experience in DRAM-board layout is a great teacher. The following set of guidelines, gleaned from experienced memory-system designers, provides a basic framework for laying out a DRAM board.

First, try to limit the length of a board trace to less than 8 in. If you're using surface-mount components, you can extend the trace-length limit to 10 in. Surface-mount devices (SMDs) have less intrinsic inductance

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and capacitance than their DIP counterparts, so SMDs present a smaller load.

Second, don't distribute more than 16 DRAMs over a single trace; 16 DRAMs present a distributed capacitive load of approximately 120 pF on the line. Because SMDs have reduced input capacitance, you can extend the DRAM count to 20 by using SMDs.

Third, although computer simulations are valuable tools for evaluating a board layout, you should always build a prototype board to measure the board's characteristics. In general, simulations provide only an approximation of an actual layout.

Finally, always use worst-case specifications to evaluate a design or a board layout. A worst-case analysis gives you adequate design margin. For example, if the high-to-low transition time for a driver is specified as 4 nsec and the low-to-high time is specified as 7 nsec, always use the 7-nsec value as a design parameter for that buffer. Also, if a manufacturer specifies only typical values and no worst-case values for a particular part, try to estimate the worst-case value by measuring a representative sample of similar parts or consult another manufacturer's specification for a similar part. EDN

Authors' biographies

Fred Tabaian is an applications engineer for Texas Instruments (Dallas, TX), where he's currently toolkit program manager. He has been with TI for six years, before which he was self-employed. Fred obtained a BSEE from the University of Iowa and an MSEE from Texas Tech University. In his spare time, he enjoys horseback riding, speed boats, and racquetball.

Marlene M Toomer is an applications engineer in TI's Semiconductor Div (Dallas, TX). She's responsible for the development and support of ASIC modules. Marlene, who has worked at TI for four years, graduated from Louisiana State University with a BSEE. Her pastimes include tennis, softball, aerobics, and needlepoint.

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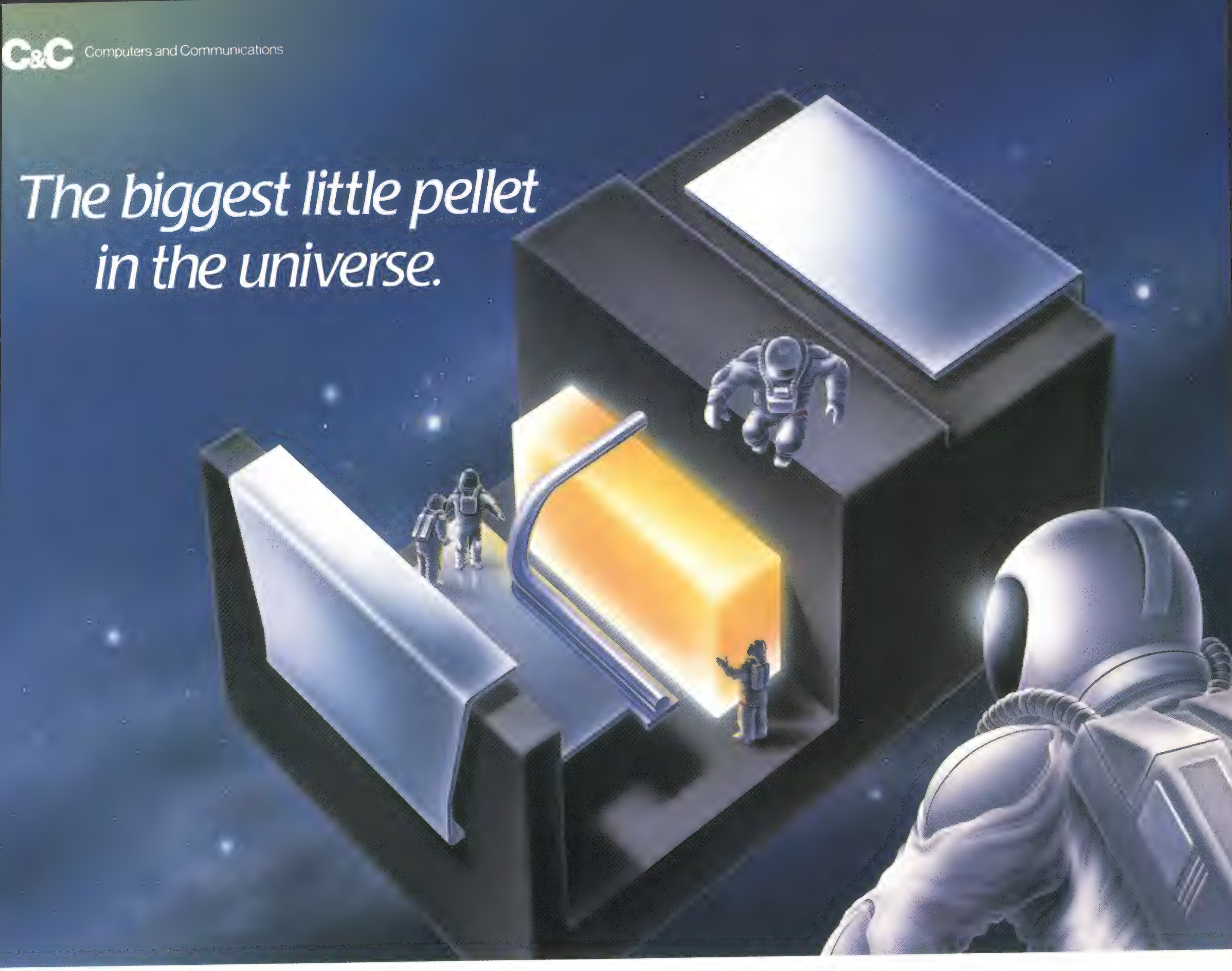

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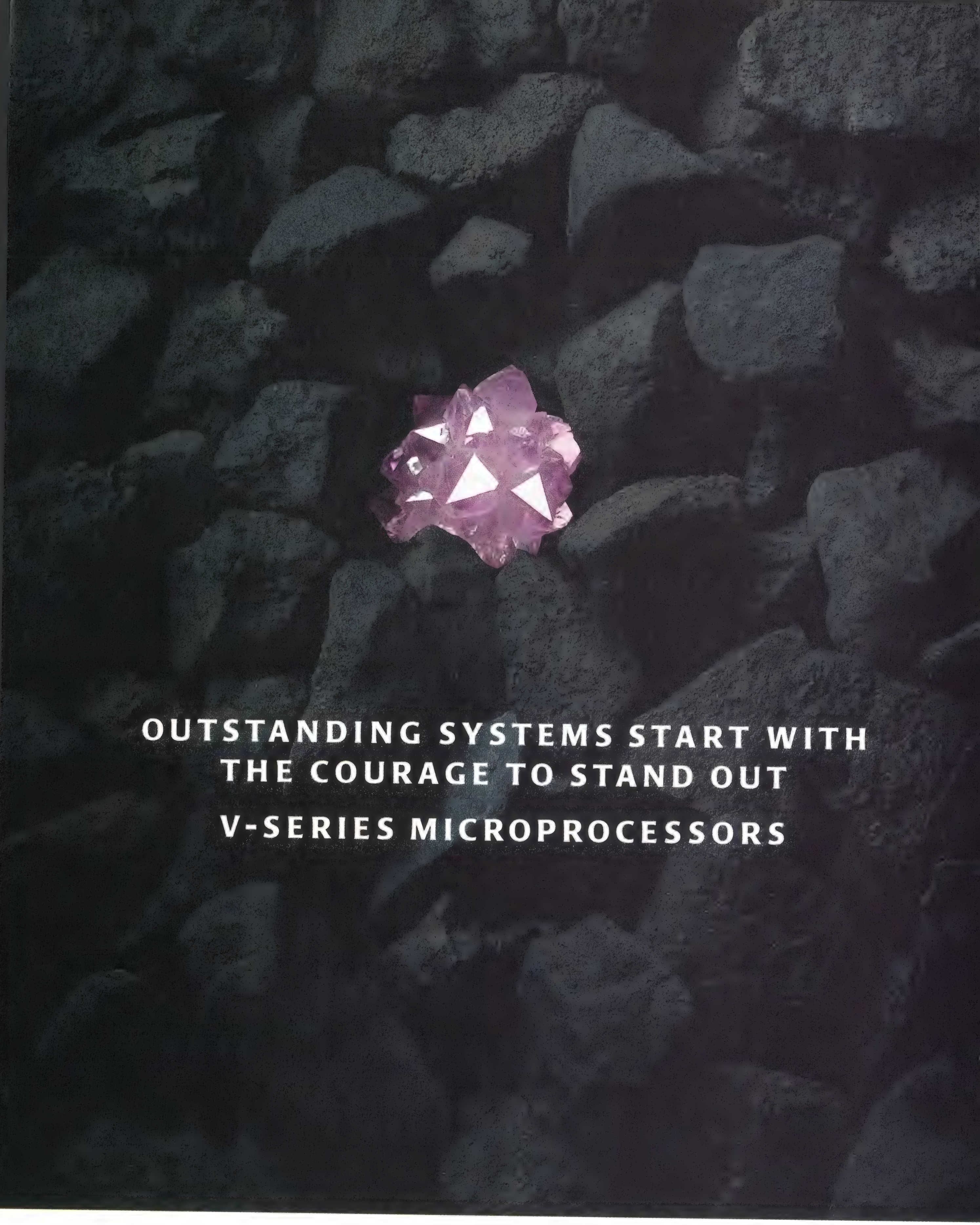

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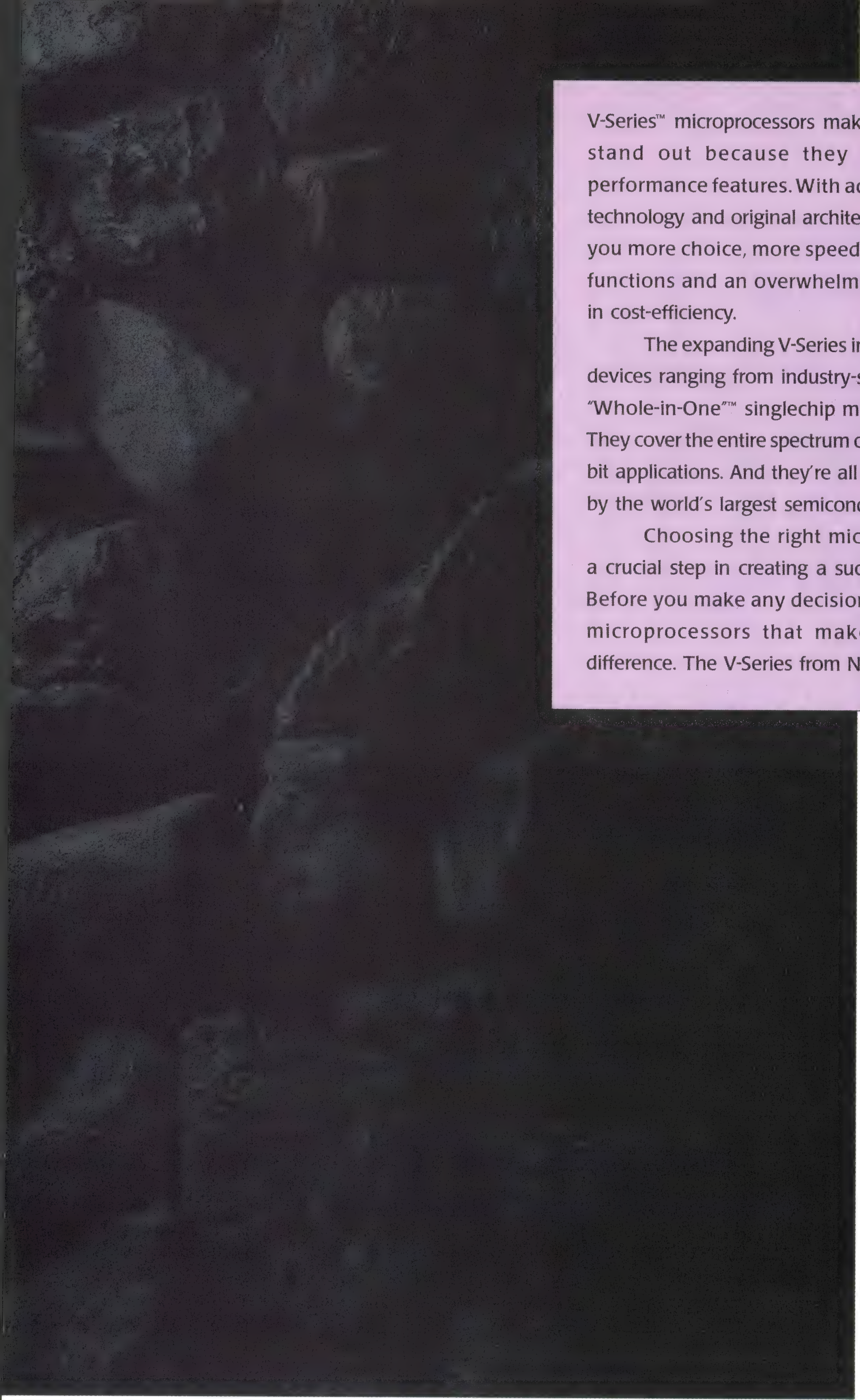

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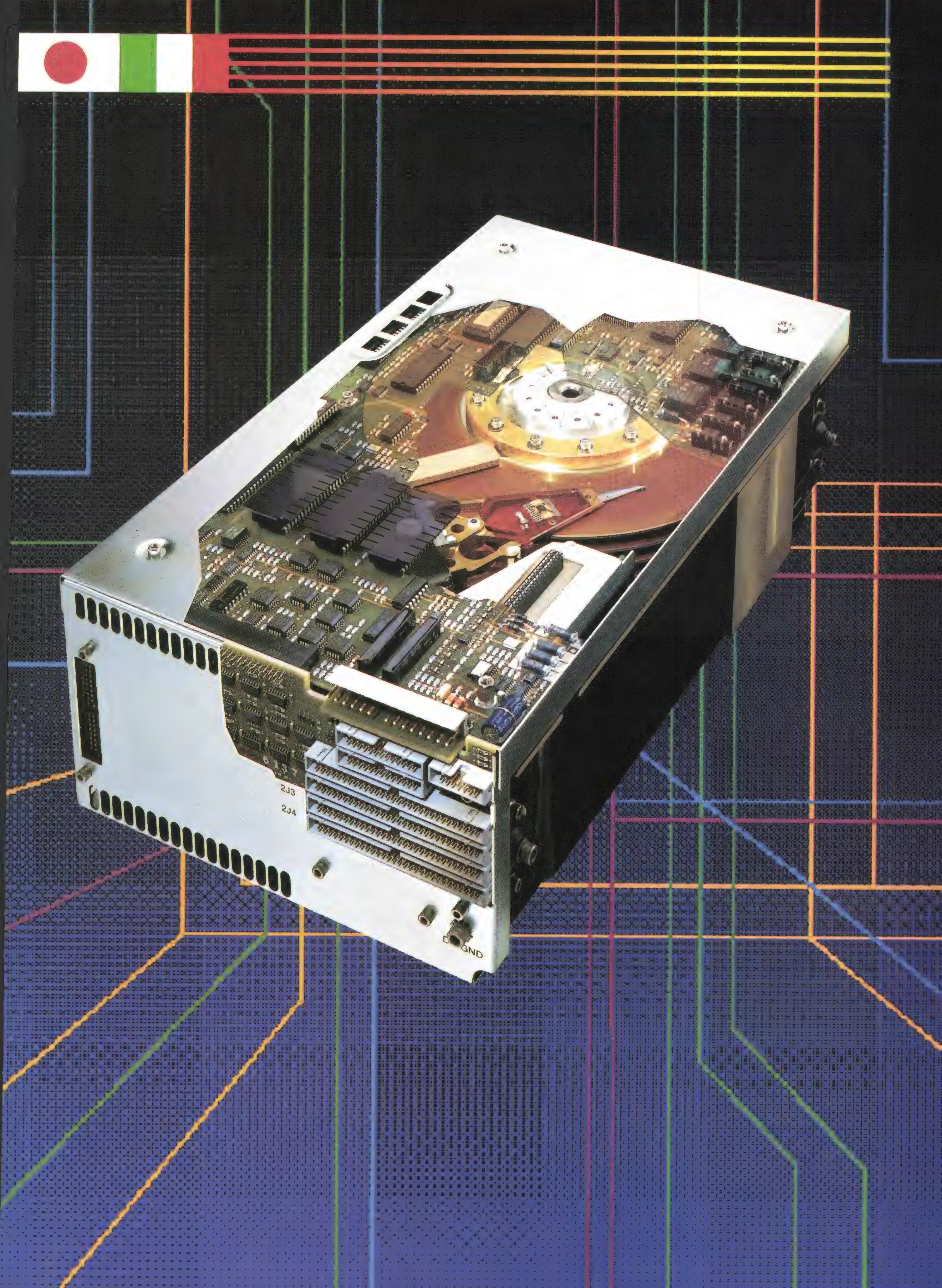
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Amplitude-locked loop speeds filter test

Steven C Hageman
Calex Manufacturing Co Inc, Pleasant Hill, CA

The circuit shown in **Fig 1** finds, locks to, and displays the cutoff frequency of an audio-frequency lowpass filter. The circuit compares the rms input to the filter-under-test with the filter's rms output. Based on the results of this comparison, the circuit adjusts a VCO to achieve a null at the desired input-to-output attenuation of the filter. Hence, its operation is similar to that of a phase-locked loop.

The AD536 rms-to-dc converter connected to the filter input acts as a reference to the LT1013 servo amplifier. You set the null-voltage potentiometer to the desired input-signal attenuation, such as −3 dB. The servo loop adjusts the VCO's frequency until the output of the filter's rms-dc converter equals the null voltage.

The ICL8038 waveform generator is connected as a sine-wave oscillator with a wide-sweep input range of 1000 to 1. The values given in **Fig 1** provide you with a sweep range of 20 Hz to 20 kHz. The LT1042 window comparator senses when the null voltage and the filter output voltage are within ±15 mV of each other and causes the loop-locked LED to turn on. When the loop reaches lock, you can read the filter's cutoff frequency from the frequency counter.

The loop's bandwidth is 16 Hz, and it has 50° of phase margin. The circuit acquires lock in less than one second with frequency repeatability of better than 0.1%. You can increase the loop bandwidth—at the expense of accuracy—by reducing the value of the integration capacitor, C_1, and the values of the averaging capacitors around the rms-dc converters. EDN

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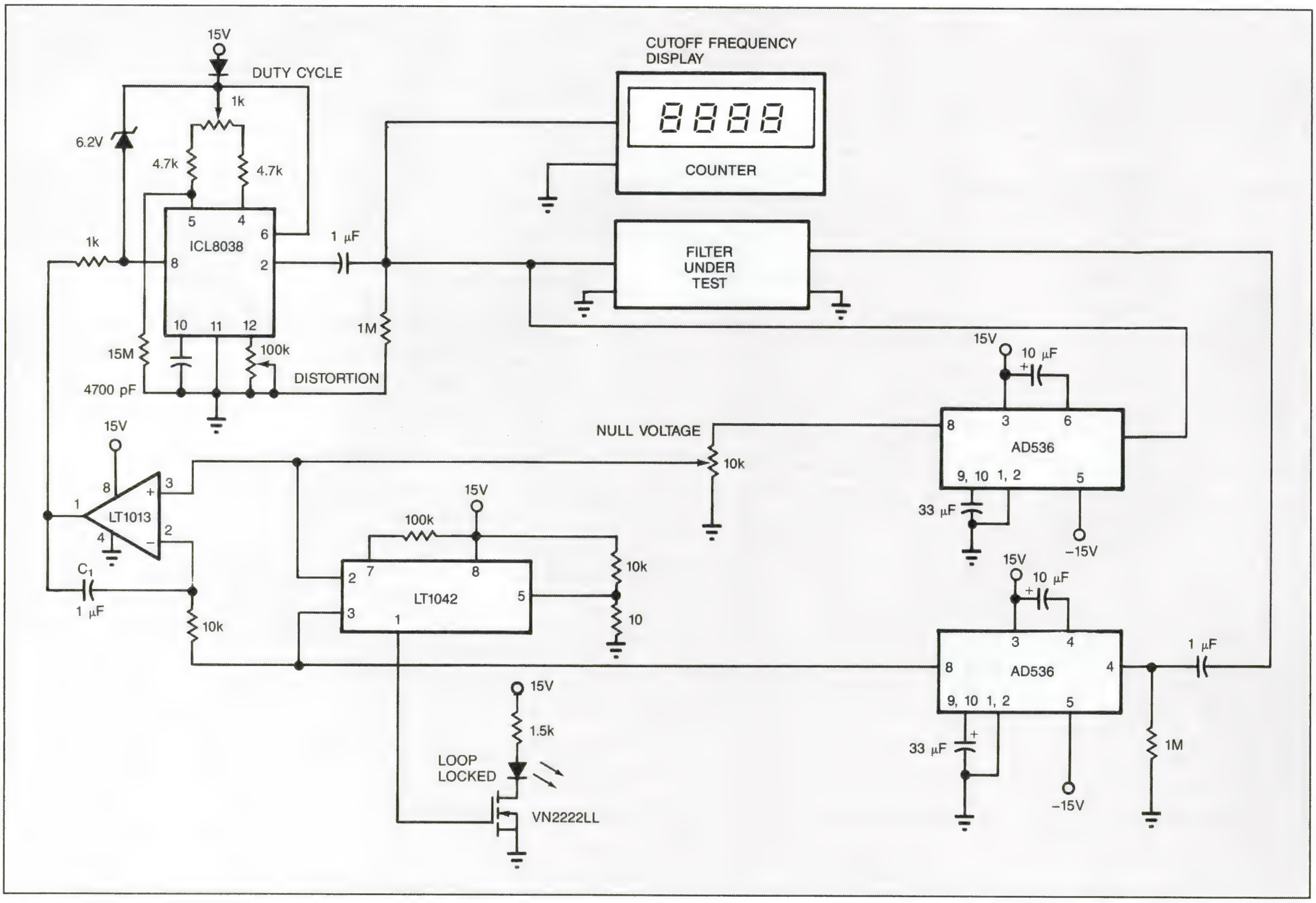

***Fig 1—You can use this amplitude-locked-loop circuit** to find the cutoff frequency of a lowpass filter.*

Mux scans input to find largest voltage

Glenn DeMichele
Harris Semiconductor, Wood Dale, IL

Operating from clock frequencies of dc to 750 kHz, the circuit shown in **Fig 1** can scan as many as 16 analog inputs to determine which channel has the largest input voltage. With a clock frequency of 600 kHz, the circuit completes its input scan in 30 μsec.

Sixteen analog input voltages simultaneously drive the inputs of two multiplexers, IC_1 and IC_2. A 4-bit binary counter, IC_4, drives IC_1, thus causing it to sequentially scan all 16 input voltages. IC_3 compares the output voltage of IC_2 to the 16 inputs scanned by IC_1. If IC_3 finds an input that is larger than the output of IC_2, the comparator output goes high, which latches the channel number of this larger voltage into IC_5. Because IC_5 stores the channel number of the highest input voltage and provides the address select for IC_2, the output of multiplexer IC_2 is the largest input voltage.

The resistive dividers at the inputs of IC_3 reduce the multiplexer output voltage to values that are within the common-mode range of the LM311. The 150-kΩ resistor slightly unbalances the inputs, so that an input voltage must be 30 to 40 mV above the voltage at the output of IC_2 before that voltage is latched into IC_5. This effective hysteresis also stabilizes IC_5's output. EDN

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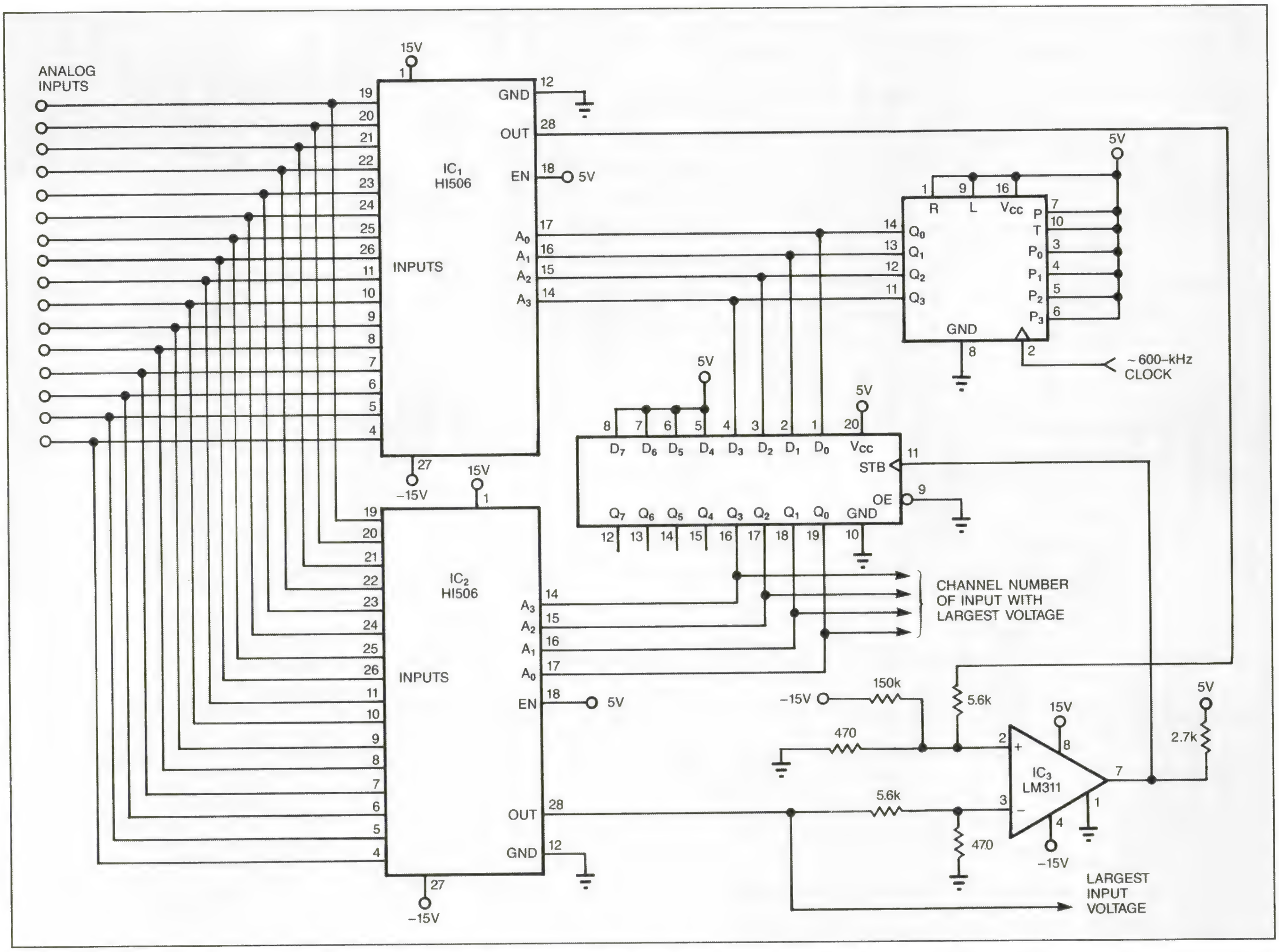

*Fig 1—**To find and hold the address of the input** with the largest voltage, IC_3 compares the output of two multiplexers; when IC_1's output is greater than IC_2's output, IC_1's input-channel address is latched into IC_5.*

Program calculates BPF component values

Bob Mostafapour
Dow Corning Corp, Midland, MI

Based on the values you specify for f_0 and Q, the Basic program in **Listing 1** finds standard component values for the band-pass-filter circuit shown in **Fig 1. Fig 1**'s filter implementation exhibits high Q and low gain sensitivity. The transfer function of the filter is

$$T(s) = \frac{-s\left(\frac{R_1 + R_2}{RCR_1}\right)}{s^2 + s\left(\frac{2R_1 - NR_2}{NRCR_1}\right) + \frac{1}{NR^2C^2}},$$

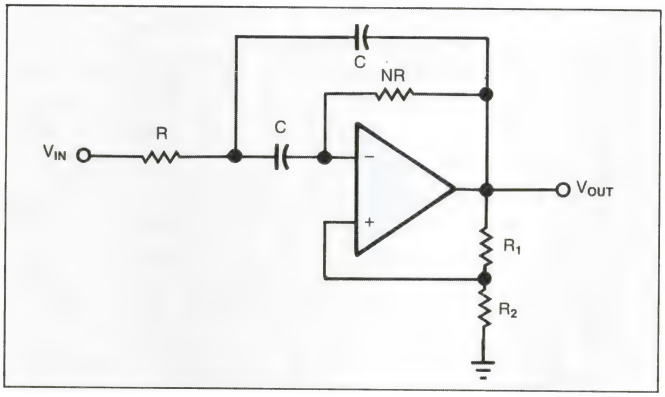

*Fig 1—**This bandpass filter exhibits high Q** and low gain sensitivity.*

LISTING 1 — BANDPASS FILTER DESIGN PROGRAM

```
10 CLS
20 PI=3.14159265#
30 DIM R(80).C(36)
40 DATA 10,12,15,18,22,27,33,39,47,56,68,82
50 DATA 10,12.15,18,20,22,24,27,30,33,36,39,43,47,51,56,62,68,75,82
60 FOR I=1 TO 12
70 READ CX
80 C(I)=CX*1E-10
90 C(I+12)=CX*1E-09
100 C(I+24)=CX*1E-08
110 NEXT I
120 FOR I = 1 TO 20
130 READ RX
140 R(I)=RX*100
150 R(I+20)=RX*1000
160 R(I+40)=RX*10000
170 R(I+60)=RX*100000!
180 NEXT I
190 PRINT" Please input the Q and the percent tolerance on Q, separated by a comma:"
200 INPUT Q,QTOL
210 PRINT"Please input the Center frequency and the percent tolerance as done above:"
220 INPUT F,FTOL
230 PRINT:PRINT"Do you want to enter a capacitor of your choosing? (1=Yes)"
240 INPUT R
250 IF R=1 THEN INPUT "input the value in uF:";CI
260 CI=CI*.000001
270 INPUT "input the lower, upper limit for resistors (1 to 8200K-ohms)";RLL,RUL
280 IF RLL<1 THEN RLX=1
290 IF RUL>8200 THEN RUX=80
300 FOR S=1 TO 80
310 IF RLX=0 AND RLL*1000<R(S) THEN RLX=S-1
320 IF RLX=0 AND RLL*1000=R(S) THEN RLX=S
330 IF RUX=0 AND RUL*1000=R(S) THEN RUX=S
340 IF RUX=0 AND RUL*1000<R(S) THEN RUX=S-1
350 NEXT S
360 IF R = 1 THEN 460
370 INPUT "input the lower, upper limit for capacitors (.001 to .82uF)";CLL,CUL
380 IF CLL<.001 THEN CLX=1
390 IF CUL>.82 THEN CUX=36
400 FOR S=1 TO 36
```

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	end, min.	200	400	600	800	1200	1200	1600	1600	1600	1800	2000	2100	2200
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*Prefix P for pins, B for BNC, N for Type N, S for SMA   example PLP-10.7

C105 REV. E

LISTING 1 — BANDPASS FILTER DESIGN PROGRAM *(continued)*

```
410 IF CUX=0 AND CUL/1000000!=C(S) THEN CUX=S
420 IF CLX=0 AND CLL/1000000!<C(S) THEN CLX=S-1
430 IF CLX=0 AND CLL/1000000!=C(S) THEN CLX=S
440 IF CUX=0 AND CUL/1000000!<C(S) THEN CUX=S-1
450 NEXT S
460 CLS
470 PRINT"  Q        Fo      C(uF)        R          NR          R1          R2"
480 PRINT"------------------------------------------------------------------------------"
490 FOR B = 1 TO INT(4*Q^2)
500 IF INT(SQR(B))^2<>B THEN 790
510 XCI = CUX
520 IF CI<> 0 THEN XCI=1:C(1)=CI
530 IF CLX=0 THEN CLX=1
540 FOR L=CLX TO XCI
550 FOR M=RLX TO RUX
560 'Pick R
570 FOR T=RLX TO RUX
580 IF SQR(B)*R(M)=R(T) THEN 610
590 NEXT T
600 GOTO 760
610 FO=1/(2*PI*SQR(B)*R(M)*C(L))
620 IF F>FO*(1+.01*FTOL) OR F<FO* (1-.01*FTOL) THEN 760
630 FOR K=RLX TO RUX
640 'pick R1
650 FOR J=RLX TO RUX
660 'pick R2
670 QD=(2*R(K)/R(J)-B)
680 IF QD<.000001 OR QD >1000000! THEN 720
690 QO=(R(K)/R(J)*SQR(B))/QD
700 IF Q>QO*(1+.01*QTOL) OR Q<QO*(1-.01*QTOL) THEN 720
710 PRINT USING " ##.##  ######,.   #.####   ####,.#    ####,.#    ####,.#    ###,.#";
QO,FO,C(L)*1000000!,R(M)/1000,R(M)*SQR(B)/1000,R(K)/1000,R(J)/1000
720 A$=INKEY$:IF A$<>"" THEN END
730 NEXT J
740 A$=INKEY$:IF A$<>"" THEN END
750 NEXT K
760 A$=INKEY$:IF A$<>"" THEN END
770 NEXT M
780 NEXT L
790 NEXT B
```

where N is an integer. The feedback divider formed by R_1 and R_2 divides the output voltage by the factor

$$b = R_2/(R_1 + R_2).$$

By inserting b in the original transfer function, you obtain this simplified transfer function:

$$T(s) = \frac{s\left[\frac{-1}{RC(1-b)}\right]}{s^2 + s\left[\frac{2(1-b) - Nb}{NRC(1-b)}\right] + \frac{1}{NR^2C^2}}$$

From this last equation you can solve for the filter parameters to obtain

$$Q = \frac{(R_1/R_2)\sqrt{N}}{2(R_1/R_2) - N}$$

and

$$f_0 = \frac{1}{2\Pi\sqrt{N}\,CR}.$$

The iterative program uses these last two equations to find standard component values that satisfy the requirements and tolerances you enter for Q and f_0. You must enter the desired component ranges; and, if you wish, you can specify the value of C. EDN

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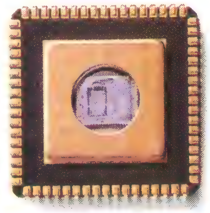

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Program aids third-order LPF design

Horace T Jones *Consultant, Rockville, MD*

The Basic program in **Listing 1** calculates component values for the lowpass-filter circuit shown in **Fig 1**.

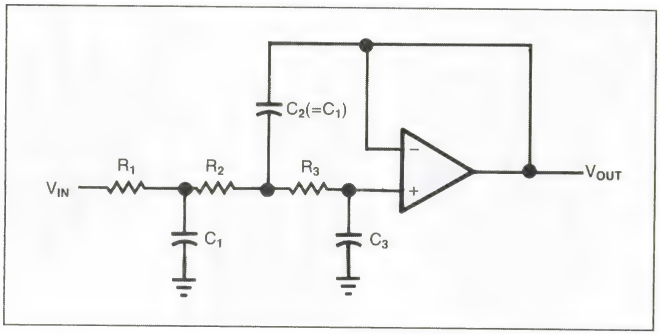

***Fig 1—By letting you choose the value of C_1,** and thus the values of C_2 and C_3, the program in **Listing 1** avoids calculations that result in nonstandard capacitor values for this lowpass filter.*

You enter the desired cutoff frequency and the value of C_1; the program calculates R_1, R_2, R_3, and C_3. You can enter your own filter poles, or you can select them from these common filter types: Bessel, Butterworth-Thomson (m = 0.6), Butterworth, and Chebyshev (0.1-, 0.5-, and 1-dB ripple). C_1 and C_2 have the same value, and C_3 will equal C_1, $C_1/10$, or $C_1/100$ depending on the type of filter you select. The closest 1% resistor values to those calculated are also reported in the output listing.

EDN

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LISTING 1 — THIRD-ORDER LOWPASS FILTER PROGRAM

```
10 CLS
20 PRINT"     Program LP3NI                    H.T.Jones                DEC 26 88"
30 PRINT
40 PRINT"  This program solves for the component values of a 3rd-order LPF using
50 PRINT" a unity-gain op-amp. It will solve for the following standard types,
60 PRINT" or you may enter the poles for your filter.
70 DEFDBL A,B,C,E,F,G,K,M,P,R,S,T,X
80 DIM RROUND(97)
90 TWOPI = 2*3.1415926536#: PRINT
100 PRINT"                       1. Bessel
110 PRINT"                       2. Butterworth-Thomson  m = 0.6
120 PRINT"                       3. Butterworth
130 PRINT"                       4. Chebyshev,  0.1 dB ripple
140 PRINT"                       5. Chebyshev,  0.5 dB ripple
150 PRINT"                       6. Chebyshev,  1.0 dB ripple
160 PRINT"                       7. Your Filter's Poles
170 PRINT
180 INPUT"                Enter your selection [1,2,3,4,5,6 or 7]: ", K$
190 PRINT
200 IF K$ = "1" GOTO 270
210 IF K$ = "2" GOTO 280
220 IF K$ = "3" GOTO 290
230 IF K$ = "4" GOTO 300
240 IF K$ = "5" GOTO 310
250 IF K$ = "6" GOTO 320
260 IF K$ = "7" GOTO 330
270 A3 = 0.360780# :A2 = 1.232956#: A1 = 1.755671#: GOTO 380
280 A3 = 0.531805# :A2 = 1.488926#: A1 = 1.858818#: GOTO 380
290 A3 = 1.000000# :A2 = 2.000000#: A1 = 2.000000#: GOTO 380
300 A3 = 1.635964# :A2 = 2.283543#: A1 = 2.229696#: GOTO 380
310 A3 = 2.223447# :A2 = 2.386141#: A1 = 2.503819#: GOTO 380
320 A3 = 2.671361# :A2 = 2.411443#: A1 = 2.759769#: GOTO 380
330 INPUT"                                   Enter the real pole: ", RP
340 INPUT"                Enter the real part of the complex pole-pair: ", RE
350 INPUT"             Enter the imaginary part of the complex pole-pair: ", IM
```

LISTING 1 — THIRD-ORDER LOWPASS FILTER PROGRAM *(continued)*

```
360 ALPHA = RP: BETA = 2*RE: GAMMA = RE^2 + IM^2
370 A3=1/(ALPHA*GAMMA): A2=(ALPHA+BETA)*A3: A1=(ALPHA*BETA+GAMMA)*A3: PRINT
380 INPUT"                    -3.0103 dB Frequency [Hz] =   ", F3
390 INPUT"                                 C1 [farads] =   ", C1
400 PRINT
410 P = 1                              'P = C3/C1
420 FOR I = 1 TO 3                     'get K, decreasing P by 10 as needed
430   K = 0: A3CALC = 0
440   WHILE A3CALC < A3
450     GOSUB 770
460     A3CALC = T*T*T * K*(1-K)*P*M
470     IF K >= 0.9 THEN 510
480     IF A3CALC >= A3 THEN 530
490     K = K + 0.1#
500   WEND
510   P = P/10
520 NEXT I
530 ST = 0.1
540 FOR I = 1 TO 4                      get closer value of K
550       K = K - ST: ST = ST/100: A3CALC = 0
560       WHILE A3CALC < A3
570         GOSUB 770
580         A3CALC = T*T*T * K*(1-K)*P*M
590         IF A3CALC >= A3 THEN 620
600         K = K + ST
610       WEND
620 NEXT I
630 R = T/(TWOPI*F3*C1)
640 R1 = R*(1-K): R2 = R*K: R3 = R*M: C3 = C1*P
650 RR = R1: GOSUB 840
660 PRINT USING"                   R1 = #.######^^^^ ohms"; R1;
670 PRINT USING"        1% value: ####### ohms"; RR
680 RR = R2: GOSUB 840
690 PRINT USING"                   R2 = #.######^^^^ ohms"; R2;
700 PRINT USING"        1% value: ####### ohms"; RR
710 RR = R3: GOSUB 840
720 PRINT USING"                   R3 = #.######^^^^ ohms"; R3;
730 PRINT USING"        1% value: ####### ohms"; RR
740 PRINT USING"              C1 = C2 = #.######^^^^ farads"; C1
750 PRINT USING"                   C3 = #.######^^^^ farads"; C3
760 END
770 A = 3*K - 2 - K*K*(P+1) - (2*P)*(1-K)   'subroutine GetK
780 B = A1 * (2-K)
790 X = B*B + 4*A*A2
800 IF X < 0 THEN 830
810 T = (-B-SQR(X))/(2*A)
820 M = A1/(T*P)-((1-K)*(P+1))/P - K
830 RETURN
840 MM = 0                            'get the closest 1% value resistor
850 WHILE RR > 10
860   RR = RR/10
870   MM = MM+1
880 WEND
890 FOR N = 1 TO 97                     'generate the 1% values
900  RX = 10^((N-1)/96)                 'RX is raw one percent value
910  RROUND(N) = FIX(100*RX+.5)/100     'RROUND is RX rounded to 2 decimal places
920  IF RROUND(N) >= RR THEN 940        'exit loop when RROUND(n) >= RR
930 NEXT N
940 E1 = ABS(RROUND(N-1)-RR)/RR: E2 = ABS(RROUND(N)-RR)/RR
950 IF E1<=E2 THEN RR = (10^MM)*RROUND(N-1) ELSE RR = (10^MM)*RROUND(N)
960 RETURN
```

TMS320 code generates pseudorandom noise

John Nangeroni
Voice Processing Corp, Cambridge, MA

The pseudorandom-noise-generator routine in **Listing 1** works in the same manner as a hardware design consisting of a shift register and XORed feedback terms (**Fig 1**). By choosing the appropriate feedback terms, you force the shift register to cycle through all possible combinations of states—except all zeros—before repeating any of them. The 5-bit generator shown in **Fig 1** sequences through 31 states in a random order.

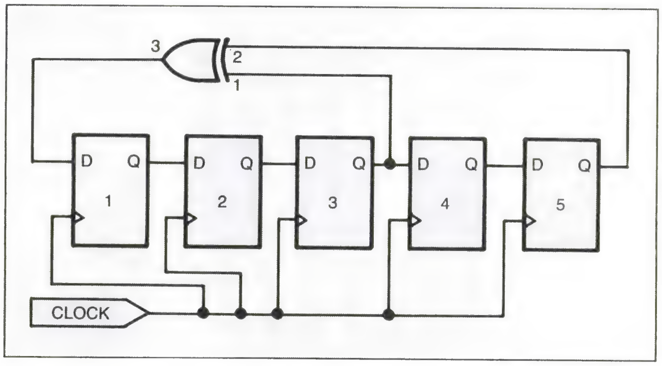

***Fig 1—The algorithm in Listing 1** generates pseudorandom noise and is based on the same principle as this hardware generator.*

The TMS320 assembly-language code in **Listing 1** generates word lengths of 15. The algorithm allows the word-length output to be any length up to that of the generator. **Listing 1**'s generator is not the fastest possible implementation—a branching implementation would execute in fewer cycles. But it's simpler and easier to modify and maintain. EDN

To Vote For This Design, Circle No 750

LISTING 1 — PSEUDORANDOM-NOISE-GENERATOR CODE

```
NOISE:     lac   noise_word      ;get last shift register value
           andk  04000h          ;mask all but bit 15
           sacl  temp            ;save
           lac   noise_word,1    ;get last shift reg. value, shifted
                                 ; so that bits to be XORed line up.
                                 ; In this case, bits 14 & 15, so << 1
           andk  04000h          ;mask all other bits
           xor   temp            ;now XOR
           bz    NZ1             ;test result
           lack  1               ;if non-zero, preload '1' into lsb
                                 ;  otherwise, lsb will be zero
NZ1:       add   noise_word,1    ;add shifted register
           sacl  noise_word      ;save
           call  output_routine  ;acc contains new value, or use
                                 ;  noise_word as source
           ret                   ;that's it
```

FEEDBACK & AMPLIFICATION

EDN is starting Feedback & Amplification to provide you with a specific place to correct, comment on, and elaborate on Design Ideas that have appeared in recent issues. We encourage you to use this column to express your opinions or suggest improvements to specific Design Ideas. Please address your letters to the Design Ideas Editor, EDN, 275 Washington St, Newton, MA 02158. You can also reach us by FAX at 617-558-4470.

Refine and extend multiply routine

Donald E Powers
Cardinal Microsystems, Marion, MA

There is an error in my Design Idea, "Routine extends multiply instruction," which appeared in EDN on October 27, 1988, pg 330. The line beginning at location OF29 should read as follows:

OF29 FC MOV R4,A; – >R4 partial product

A second error occurs in the opcode at location OF1D; it should be C3 rather than E3.

My idea converts the original version of an unsigned multiply algorithm that used 32-bit integers for use in the 8051 µC series. The code is part of a mathematical package for remote-instrument data reduction. Since submitting it to EDN, I have refined and reduced the code for a 16-bit-only multiply (see **Listing 1**). Because the algorithm is more important than the actual code, I encourage readers to extend it to other processor and multiply sizes.

LISTING 1—16-BIT-ONLY MULTIPLY ROUTINE

```
OF00                    ORG  OF00H
OF00 EE       MUL16:    MOV  A,R6         ;Do highest partial
OF01 8CFO               MOV  B,R4         ;product first.
OF03 A4                 MUL  AB
OF04 COFO               PUSH B            ;R6*R4 Hi
OF06 COEO               PUSH ACC          ;R6*R4 Lo
OF08 EE                 MOV  A,R6
OF09 8DFO               MOV  B,R5
OF0B A4                 MUL  AB
OF0C COFO               PUSH B            ;R6*R5 Hi
OF0E COEO               PUSH ACC          ;R6*R5 Lo
OF10 EF                 MOV  A,R7
OF11 8CFO               MOV  B,R4
OF13 A4                 MUL  AB
OF14 COFO               PUSH B            ;R7*R4 Hi
OF16 COEO               PUSH ACC          ;R7*R4 Lo
OF18 EF                 MOV  A,R7
OF19 8DFO               MOV  B,R5
OF1B A4                 MUL  AB
OF1C FF                 MOV  R7,A         ;R7*R5 Lo -> R7 Product
OF1D DOEO               POP  ACC          ;R7*R4 Lo +
OF1F 25FO               ADD  A,B          ;R7*R5 Hi
OF21 FE                 MOV  R6,A         ;-> R6 Partial Product
OF22 DOEO               POP  ACC          ;R7*R4 Hi
OF24 3400               ADDC A,#0         ;+ any previous carry
OF26 FD                 MOV  R5,A         ;-> R5 Partial product
OF27 DOEO               POP  ACC          ;R6*R5 Lo
OF29 2E                 ADD  A,R6         ;+R6 Partial Product
OF2A FE                 MOV  R6,A         ;-> R6 Product
OF2B DOEO               POP  ACC          ;R6*R5 Hi
OF2D 3D                 ADDC A,R5         ;+R5 Partial Product
OF2E FD                 MOV  R5,A         ;-> R5 Partial Product
OF2F E4                 CLR  A            ;Initial R4 to zero
OF30 3400               ADDC A,#00        ;+ any previous carry
OF32 FC                 MOV  R4,A         ;-> R4 Partial Product
OF33 DOEO               POP  ACC          ;R6*R4 Lo
OF35 2D                 ADD  A,R5         ;+R5 Partial product
OF36 FD                 MOV  R5,A         ;-> R5 Product
OF37 DOEO               POP  ACC          ;R6*R4 Hi
OF39 3C                 ADDC A,R4         ;+ R4 Partial product + C
OF3A FC                 MOV  R4,A         ;-> R4 Product
OF3B 22                 RET
```

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FEEDBACK AND AMPLIFICATION

CMOS circuit guaranteed to oscillate

Carl Spearow, Senior Engineer
Sundstrand Corp, Rockford, IL

I am writing in response to the Design Idea, "CMOS circuit always oscillates," which appeared in EDN on February 2, 1989, pg 196. The author is correct: The first circuit shown may not oscillate under certain conditions. The second circuit solves the problem, but it is somewhat awkward and uses more parts than are necessary.

The circuit shown in **Fig 1** is guaranteed to oscillate at a frequency of about $2.2/(R_1 \times C)$ if $R_2 \gg R_1$. You can reduce the number of gates further if you replace gates 1 and 2 with a noninverting gate.

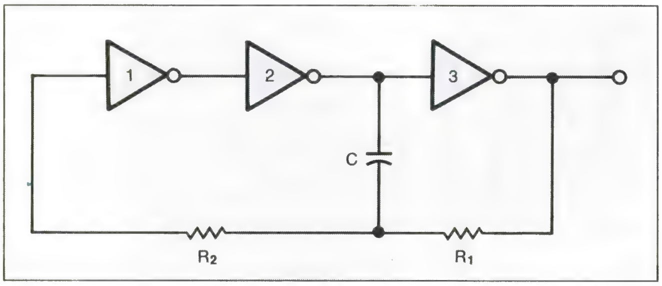

Fig 1—This circuit will never fail to oscillate.

Clarify 555 input trigger threshold

John J O'Farrell, President
The Tran-Trol Co, Tallahassee, FL

My Design Idea, "555 timer triggers on millivolt signal," which appeared in EDN on January 5, 1989, pg 208, includes an error that should be brought to your readers' attention. In the first paragraph, the last part of the second sentence should read "...no chip maker specifies a value for the threshold comparator's input-voltage triggering differential across terminals 5 and 6 of a 555 or 7555 timer." It previously read that "no chip maker specifies a value for the base current into pin 6 of a 555 timer." Every 555/7555 data sheet I have seen *does* specify the base current into terminal 6, but *none* specifies the value of the threshold comparator's input-voltage differential that is required to change the comparator output state.

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WRI 4221	+5v,3A	+12v,2.5/4A	
WRI 3031	+5v,2A	+12v,1.5/2.5A	—12v,.5A
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WM063	+5v,380mA	—12v,180mA	+12v,180mA
WM093	+5v,860mA	—5v,300mA	+12v,300mA
WM113	+5v,860mA	—12v,300mA	+12v,300mA
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CIRCLE NO 121

DESIGN NOTES

Number 22 in a series from Linear Technology Corporation May, 1989

New 12-Bit Data Acquisition Systems Communicate with Microprocessors Over 4 Wires

As board space and semiconductor package pins become more valuable, serial data transfer methods between microprocessors (MPUs) and their peripherals become more and more attractive. Not only does this save lines in the transmission medium, but, because of the savings in package pins, more function can be packed into both the MPU and the peripheral. Users are increasingly able to take advantage of these savings as more MPU manufacturers develop serial ports for their products[1-3]. However, peripherals which are able to communicate with these MPUs must be available in order for users to take full advantage. Also, MPU serial formats are not standardized so not all peripherals can talk to all MPUs.

The LTC1290 Family

A new family of 12-bit data acquisition circuits has been developed to communicate over just 4 wires to the recently developed MPU synchronous serial formats as well as to MPUs which do not have serial ports. These circuits feature software configurable analog circuitry including analog multiplexers, sample and holds, bipolar and unipolar conversion modes and the ability to shut power completely off. They also have serial ports which can be software configured to communicate with virtually any MPU. Even the lowest grade device features guaranteed ±0.5LSB linearity over the full operating temperature range. Reduced span operation, accuracy over a wide temperature range and low power single supply operation make it possible to locate these circuits near remote sensors and transmit digital data back through noisy media to the MPU. Figure 1 shows a typical hookup of the LTC1290, the first member of this data acquisition family. For more detail, refer to the LTC1290 data sheet.

Included are eight analog inputs which can common-mode to both supply rails. Each can be configured for unipolar or bipolar conversions and for single-ended or differential inputs by sending a data input (D_{IN}) word from the MPU to the LTC1290 (Figure 1).

Both the power supplies are bypassed to analog ground. The V^- supply allows the device to operate with inputs which swing below ground. In single supply applications it can be tied to ground.

The span of the A/D converter is set by the reference inputs which, in this case, are driven by a 2.5V LT1009 which gives an LSB step size of 0.61mV. However, any reference voltage within the power supply range can be used.

The 4 wire serial interface consists of an active low chip select pin ($\overline{CS}$), a shift clock (SCLK) for synchronizing the data bits, a data input (D_{IN}) and a data output (D_{OUT}). Data is transmitted and received simultaneously (full duplex), minimizing the transfer time required.

The external ACLK input controls the conversion rate and can be tied to SCLK as in Figure 1. Alternatively, it can be derived from the MPU system clock (e.g., the 8051 ALE pin) or run asynchronously. When the ACLK pin is driven at 4MHz, the conversion time is 13μs.

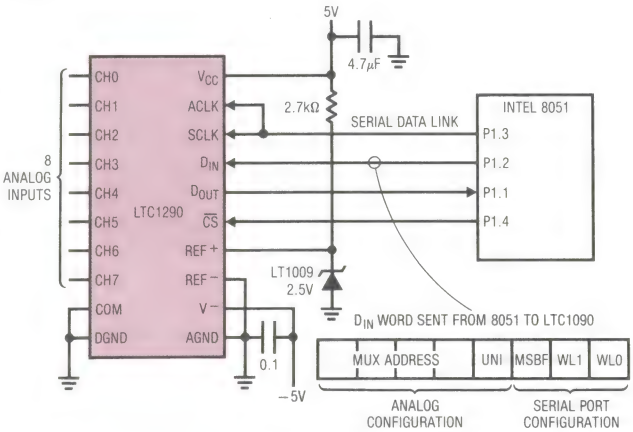

Figure 1. A Typical Hookup of the LTC1290

Advantages of Serial Communications

The LTC1290 can be located near the sensors and serial data can be transmitted back from remote locations through isolation barriers or through noisy media.

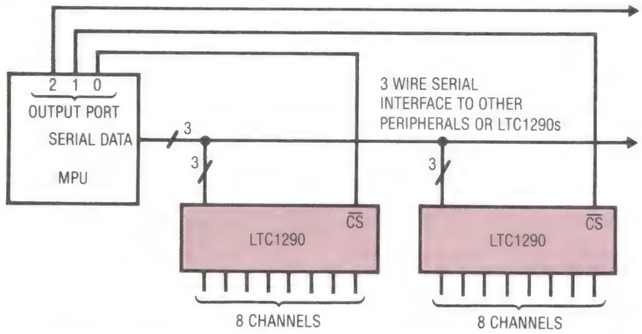

Figure 2. Several LTC1290s Sharing One 3 Wire Serial Interface

Using fewer pins for communication makes it possible to pack more function into a smaller package. LTC1290 family members are complete systems being offered in packages ranging from 20 pins to 8 pins (e.g., LTC1291, 1292, 1293, 1294).

Speed is Usually Limited by the MPU

A perceived disadvantage of the serial approach is speed. However, the LTC1290 can transfer a 12-bit A/D result in 6µs when clocked at its maximum rate of 2MHz. With the minimum conversion time of 13µs, throughput rates of 50kHz are possible. In practice, the serial transfer rate is usually limited by the MPU, not the LTC1290. Even so, throughput rates of 20kHz are not uncommon when serial port MPUs are used. For MPUs without serial ports, the transfer time is somewhat longer because the serial signals are generated with software. For example, with the Intel 8051 running at 12MHz, a complete transfer takes 96µs. This makes possible throughput rates of approximately 10kHz.

Talking to Serial Port MPUs

By accommodating a wide variety of transfer protocols, the LTC1290 is able to talk directly to almost all synchronous serial formats. The last 3 bits of the LTC1290 data input (D_{IN}) word define the serial format and power shutdown (see Figure 3). The MSBF bit determines the sequence in which the A/D conversion result is sent to the processor (MSB or LSB first). Figure 4 shows several popular serial formats and the appropriate D_{IN} word for each. Typically a complete data transfer cycle takes only about 15 lines of processor code.

WL1	WL2	Output Word Length
0	0	8 Bits
0	1	Power Shut Down
1	0	12 Bits
1	1	16 Bits

Figure 3. Word Length and Power Shutdown

Talking to MPUs without Serial Ports

The LTC1290 talks to serial port processors but works equally well with MPUs which do not have serial ports. In these cases, $\overline{CS}$, SCLK and D_{IN} are generated with software on 3 port lines. D_{OUT} is read on a fourth. Figure 4 shows the appropriate D_{IN} word for communicating with MPU parallel ports. Figure 1 shows a 4 wire interface to the popular Intel 8051. A complete transfer takes only 33 lines of code.

Sharing the Serial Interface

No matter what processor is used, the serial port can be shared by several LTC1290s or other peripherals (see Figure 2). A separate $\overline{CS}$ line for each peripheral determines which is being addressed.

Conclusions

The LTC1290 family provides data acquisition systems which communicate via a simple 4 wire serial interface to virtually any microprocessor. By eliminating the parallel data bus they are able to provide more function in smaller packages, right down to 8 pin DIPs. Because of the serial approach, remote location of the A/D circuitry is possible and digital transmission through noisy media or isolation boundaries is made easier without a great loss in speed.

Type of Interface	LTC1090 Data Format	LTC1090 D_{IN} Word: Analog Configuration					MSBF	WL1	WL0
All Parallel Port MPUs	MSB First 12 Bits	X	X	X	X	X	1	1	0
National MICROWIRE*	MSB First 12 Bits	X	X	X	X	X	1	1	0
National MICROWIRE/PLUS*; Motorola SPI	MSB First 16 Bits	X	X	X	X	X	1	1	1
Hitachi Synchronous SCI; TI TMS7000 Serial Port	LSB First 16 Bits	X	X	X	X	X	0	1	1

Figure 4. The LTC1290 Accommodates Both Parallel and Serial Ports

*MICROWIRE and MICROWIRE/PLUS are trademarks of National Semiconductor Corp.

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[1] Aleaf, Abdul, and Richard Lazovick, "Microwire/Plus," National Semiconductor, Santa Clara, CA, Wescon '86, Session 21.

[2] Derkach, Donald J., "Serial Data Transmission in MCU Systems," RCA Solid State, Somerville, NJ, Wescon '86, Session 21.

[3] Kalinka, Theodore J., "Versatile Serial Peripheral Interface (SPI)," RCA Solid State, Somerville, NJ, Wescon '86, Session 21.

For LTC1290 literature, call **800-637-5545**. For help with an application call 432-1900, Ext. 445.

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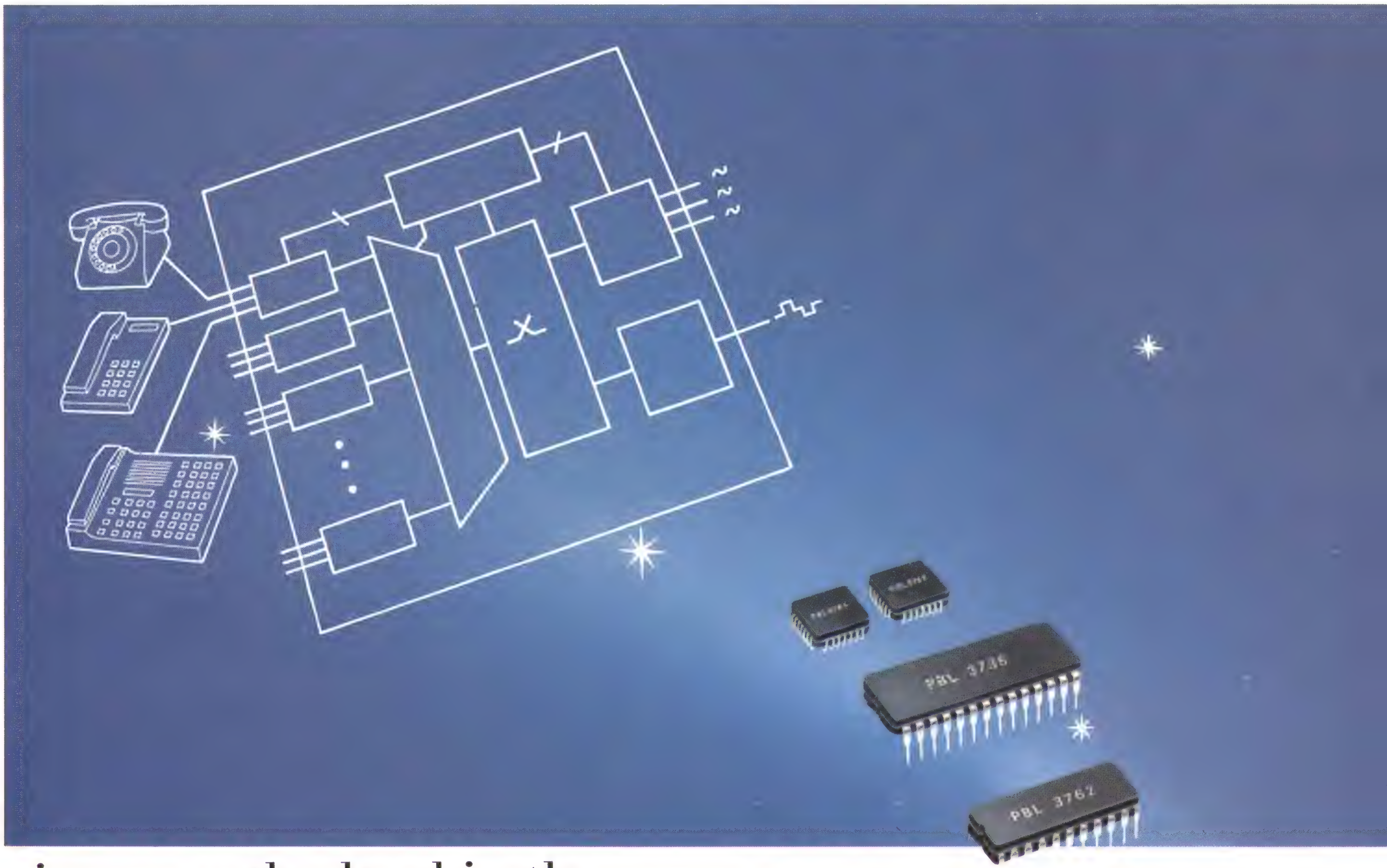

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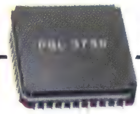

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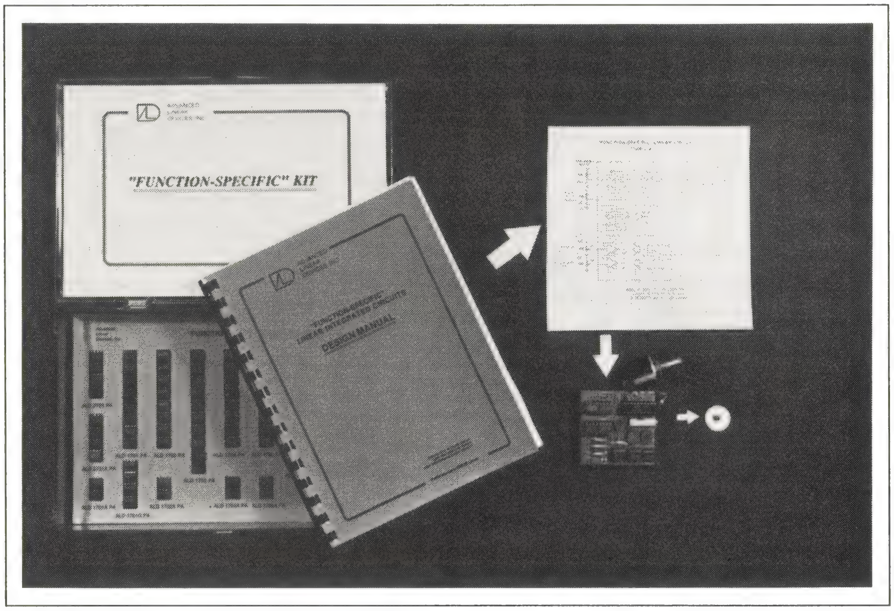

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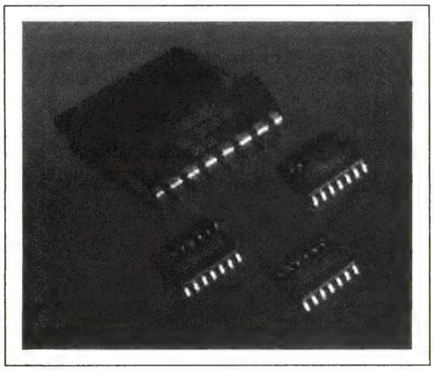

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The SD5400 Series quad analog switches feature high-speed operation and low on-resistance. Turn-on time is 0.7 nsec typ and turn-off time is 10 nsec typ. The on-resistance of the DMOS switches is typically 30Ω at a drain current of 1 mA and gate-to-source voltage of 10V. The devices also feature a low analog-input capacitance of 3.5 pF and an output capacitance of 1.3 pF. Crosstalk is −107 dB at 3 kHz. The SD5400 device handles ±10V analog signals, the SD5401 handles ±5V signals, and the SD5402 handles ±7.5V signals. The devices come in space-saving S0-14 packages. SD5400, $1.62; SD5401, $0.84; SD5402, $1.13 (100,000).

Calogic Corp, 237 Whitney Pl, Fremont, CA 94539. Phone (415) 656-2900.

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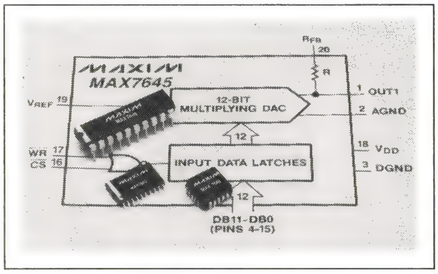
12-BIT DAC

- *Operates from a 15V supply*
- *Contains internal data-latches*

Fabricated in CMOS, the MAX7645 is a 12-bit multiplying D/A converter. The device contains internal data latches and works off a 15V supply with TTL-compatible digital inputs. The MAX7645 replaces the industry-standard AD7545, which is TTL compatible with a 5V supply in systems where the analog section



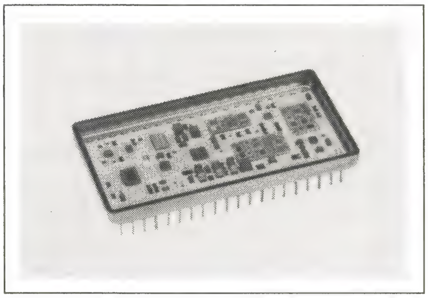
works off a 15V supply, and the digital section uses TTL logic. The MAX7645 has ±½ LSB relative accuracy, ±1LSB gain error, and guaranteed monotonicity over the temperature range. The $\overline{WR}$ pulse width of 75 nsec makes the device suitable for use with a wide range of fast 8- and 16-bit µPs. Power consumption is 30 mW with TTL inputs and 1.5 mW with 15V CMOS logic. 20-pin SO and DIP packages, from $7 (100).

Maxim Integrated Products, 120 San Gabriel Dr, Sunnyvale, CA 94086. Phone (408) 737-7600.

Circle No 353

SAMPLING ADC

- *12-bit resolution*
- *Operates to 2 MHz*



Available in a 40-pin package, the ADC-00305 features 12-bit resolution and operating speeds to 500 nsec (2 MHz). The device contains a track-and-hold amplifier, an A/D converter, data registers, 3-state output buffers, and timing circuits. The ADC-00305, which interfaces with most CPUs, is specified for operation over the temperature range of 0 to 70°C. The IC provides nine bipolar/unipolar jumper-selectable analog input ranges and requires only an encode command input to start its conversion cycle. $385. Delivery, stock to six weeks ARO.

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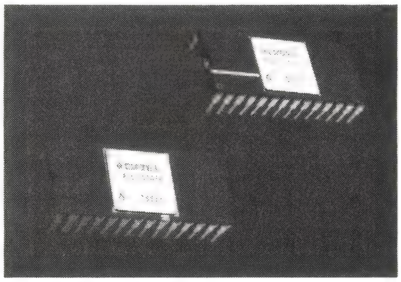


12-BIT ADC

- *Contains S/H circuit*
- *Has an internal reference and clock*

The ADC-574Z and ADC-674Z are 12-bit, µP-compatible A/D converters. Both devices, which are upgraded over earlier products, contain an on-chip sample/hold circuit, an internal reference, and a clock. The devices are pin-compatible with industry-standard HI574A/674A types. Conversion time is 25 µsec for the ADC-574Z and 15 µsec for the ADC-674Z. The addition of the S/H feature with an input-conversion capability to 5 kHz reduces the need for an external device. Other features include 3-state outputs and a digital-interface circuit, which allows direct connection to the µP address bus and control lines. 28-pin ceramic DIP, $36.20.

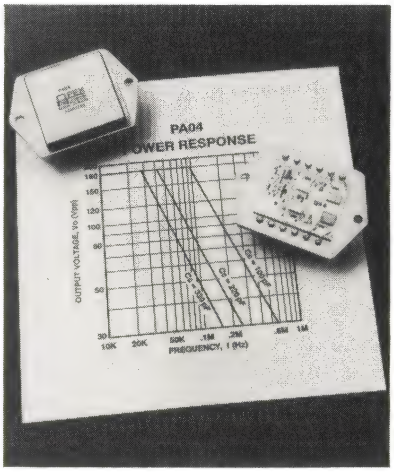
Datel Inc, 11 Cabot Blvd, Mansfield, MA 02048. Phone (508) 339-3000. FAX 508-339-6356. TLX 174388.

Circle No 355

POWER OP AMP

- *Features a 200W power rating*
- *Has 20A output current rating*

Featuring a power-dissipation rating of 200W, the PA04 power op amp has an output current rating of 20A and can operate at supply voltages to ±100V. The op amp also features a typical slew rate of 50V/μsec and a power bandwidth of 90 kHz at 180V p-p output. The PA04 can deliver 200W into a 4Ω load with <0.01% distortion. A sleep-mode pin shuts off the device's internal current sources and reduces the quiescent current to <5 mA, minimizing current drain in battery-operated applications.



Other features include Kelvin-sense current limiting and special boost-voltage pins for the driver stages. These pins reduce output saturation voltage and power dissipation by increasing the drive to the output stage. 12-pin Power DIP, $168 (100).

Apex Microtechnology Corp, 5980 N Shannon Rd, Tucson, AZ 85741. Phone (602) 742-8659.

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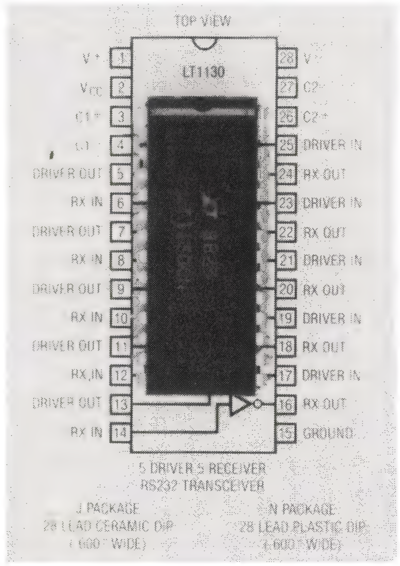

RS-232C TRANSCEIVERS

- *Operate from a 5V supply*
- *Outputs can withstand ±30V*

Fabricated in latch-up-free bipolar technology, the LT1130, LT1131, and LT1134 RS-232C transceivers

operate from a single 5V supply. All three devices feature on-chip, 9V RS-232C power-supply generators that require only 1-μF charge-pump capacitors. The LT1130 contains five drivers and five receivers; the LT1131 has five drivers and four receivers; and the LT1134 has four drivers and four receivers. These RS-232C ICs are designed so that only one transceiver is needed per serial port. In addition to eliminating latch up, the bipolar technology provides protection against damage from electrostatic discharge; the devices can withstand ± 30V without forcing current back into the power supplies. Because the RS-232C outputs are in a high-impedance state when unpowered, multiple units can reside on the same bus. LT1130 and LT1131 are available in 28-pin plastic or ceramic DIPs; the LT1134 comes in 24-pin plastic or ceramic DIPs. $5 (100).

Linear Technology Corp, 1630 McCarthy Blvd, Milpitas, CA 95035. Phone (800) 637-5545. FAX 408-434-0507.

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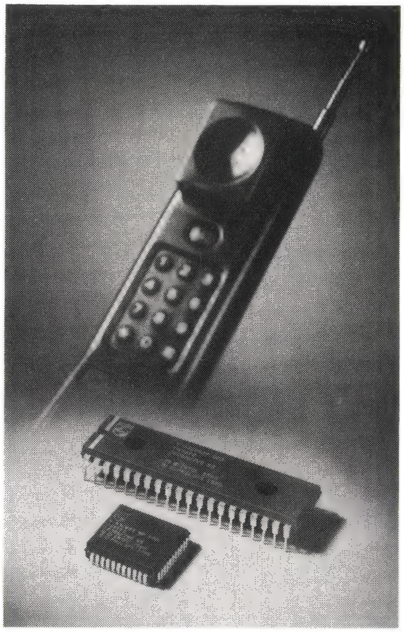

MICROCONTROLLER

- *Pin and software compatible with the 80C51*
- *Includes a 256-byte on-chip EEPROM*

Housed in a 40-pin plastic DIP or a 44-lead plastic leaded chip carrier, the PCB83C851 8-bit microcontroller is pin and software compatible with the industry-standard 80C51. However, unlike other 80C51 derivatives, it contains a 256-byte EEPROM in addition to the standard set of 80C51 on-chip memory and peripheral devices. The microcontroller also incorporates two security modes, which prevent unauthorized access to data that's held in the on-chip ROM and EEPROM. The EEPROM can withstand

10,000 write cycles and is accessed via an internal data bus that's not accessible from outside the microcontroller. In addition, program code and data in the device's 4k bytes of mask-programmed ROM cannot be accessed electrically or optically. A ROMless version, designated the PCB80C851, is available for program development and small-scale production use. Approximately Gld 18 (small qty).

Philips, Components Div, Box 218, 5600 MD Eindhoven, The Netherlands. Phone (040) 757189. TLX 51573.

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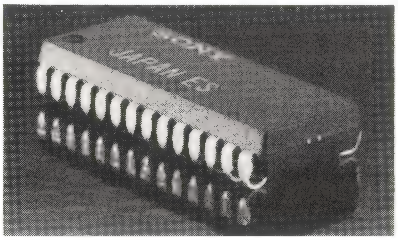
Signetics Corp, 811 E Arques Ave, Sunnyvale, CA 94088. Phone (408) 991-2000.

Circle No 359



STATIC RAMs

- *64k, 128k, and 256k bits*
- *25- to 55-nsec speed ratings*

Added to the company's static RAM product line are 16k×4-bit, 64k×4-bit, and 256k×1-bit devices. The 16k×4-bit device is available in 25-, 30- and 35-nsec versions. The 64k×4-bit and 256k×1-bit devices come in 25-, 45- and 55-nsec versions. All access-time ratings are measured under worst-case conditions from 0 to 70°C. All the devices operate from a single 5V±10% supply and are available in DIP and SOJ packages. Depending on organization and speed rating, \$21 to \$80 (1-24).

Sony Corporation of America, 10833 Valley View St, Cypress, CA 90630. Phone (714) 229-4190. FAX 714-863-0735.

Circle No 360

SMPS ICs

- *Handle normal and standby load conditions*
- *Simplify the design of TV and monitor power supplies*

The TEA2164 and TEA5170 master-slave power-supply control ICs allow you to build off-line switchmode supplies that utilize a single power transformer for both normal and standby load conditions. On the primary side, the TEA2164 slave IC provides a drive current as high as ±1.5A for a switching transistor connected to the primary winding of the power transformer. On the secondary side, the TEA5170 master monitors the fil-

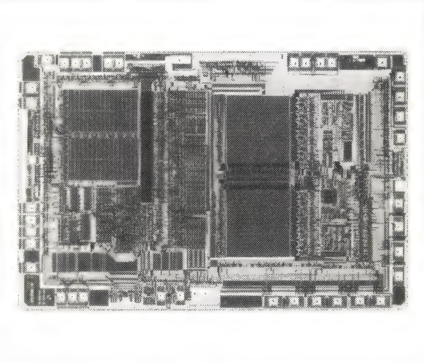
tered output voltage and generates control pulses that are fed back to the TEA2164 via a low-cost pulse transformer. Features of the TEA-2164/-5170 combination include overcurrent and overvoltage protection, automatic switch-off in the event of repetitive overcurrent conditions, and burst-mode operation to cope with standby load conditions. In standby mode the operating frequency remains high enough to eliminate the generation of audible noise. The ICs can operate at switching frequencies as high as 50 kHz, allowing you to use them in television sets at all standard line rates, and in high-resolution video monitors. TEA2164, $1.64; TEA2170, $1.32 (1000).

SGS-Thomson Microelectronics, Via C Olivetti 2, 20041 Agrate Brianza, Italy. Phone (039) 65551. TLX 330131.

Circle No 361

SGS-Thomson Microelectronics, 1000 E Bell Rd, Phoenix, AZ 85022. Phone (602) 867-6100. TLX 249976.

Circle No 362



CMOS EPROMs

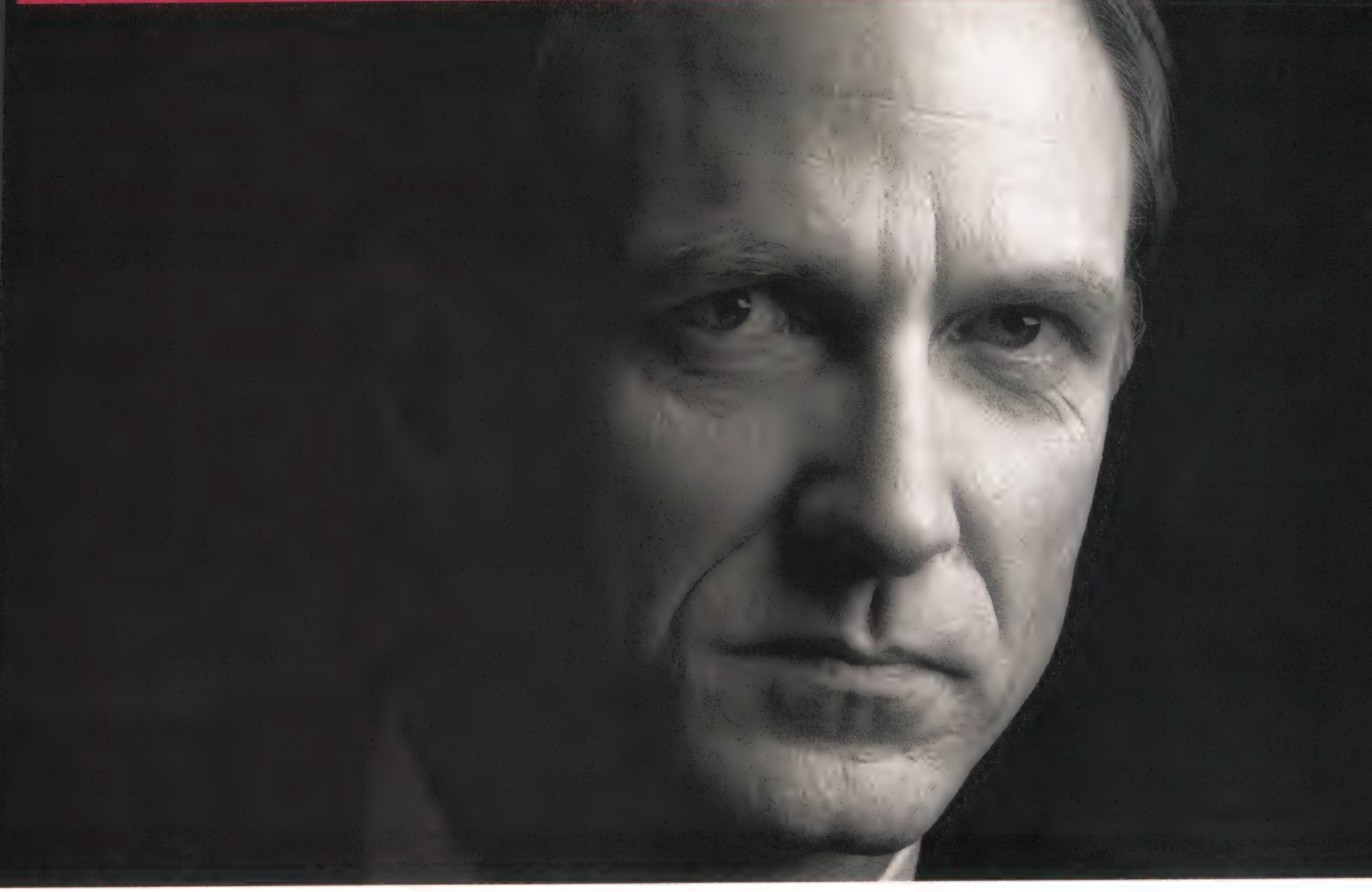
- *Available in three densities*
- *12- and 16-MHz versions are available*

Fully compatible with custom ROM-based devices, the 87C51, 87C521, and 87C541 EPROM microcontrollers are programmable on standard programmers. The 16k-byte 87C541 and 8k-byte 87C521 contain 256 bytes of RAM. The 8k-byte 87C51 device contains 128 bytes of RAM. The 541 and 521 devices contain a watchdog timer, dual data pointers, and software reset. All the devices have reduced-power idle and power-down modes. The devices are available in 40-pin DIP or 44-pin LCC packages. Both 12- and 16-MHz versions are available. 87C541, $89.10; 87C521, $78.80; 87C51, $65.20 (100).

Advanced Micro Devices Inc, Box 3453, Sunnyvale, CA 94088. Phone (408) 732-2400.

Circle No 363

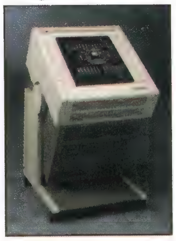
IMS The Standard In ASIC Test And Verification



"Are you betting your company on your next ASIC design?"

"The wrong decision on when to release a prototype ASIC to manufacturing can mean expensive re-masking, boards that have to be rebuilt and missed commitments to customers. Those costs can kill you. Get the information you need to make the right decision. The Logic Master can be a critical factor in reducing your level of risk. Ask IMS to show you how."

Logic Master Verification Systems from IMS provide test and verification solutions for designers of custom circuits. This complete



family of systems meets all types of hardware verification needs, from benchtop to extremely high performance. Customers at more than 500 installations have proven the performance capabilities of Logic Master Systems in the development of high-speed RISC processors, VHSIC II components and the industry's most complex ECL, GaAs and CMOS devices.

IMS

Integrated Measurement Systems™, Inc.
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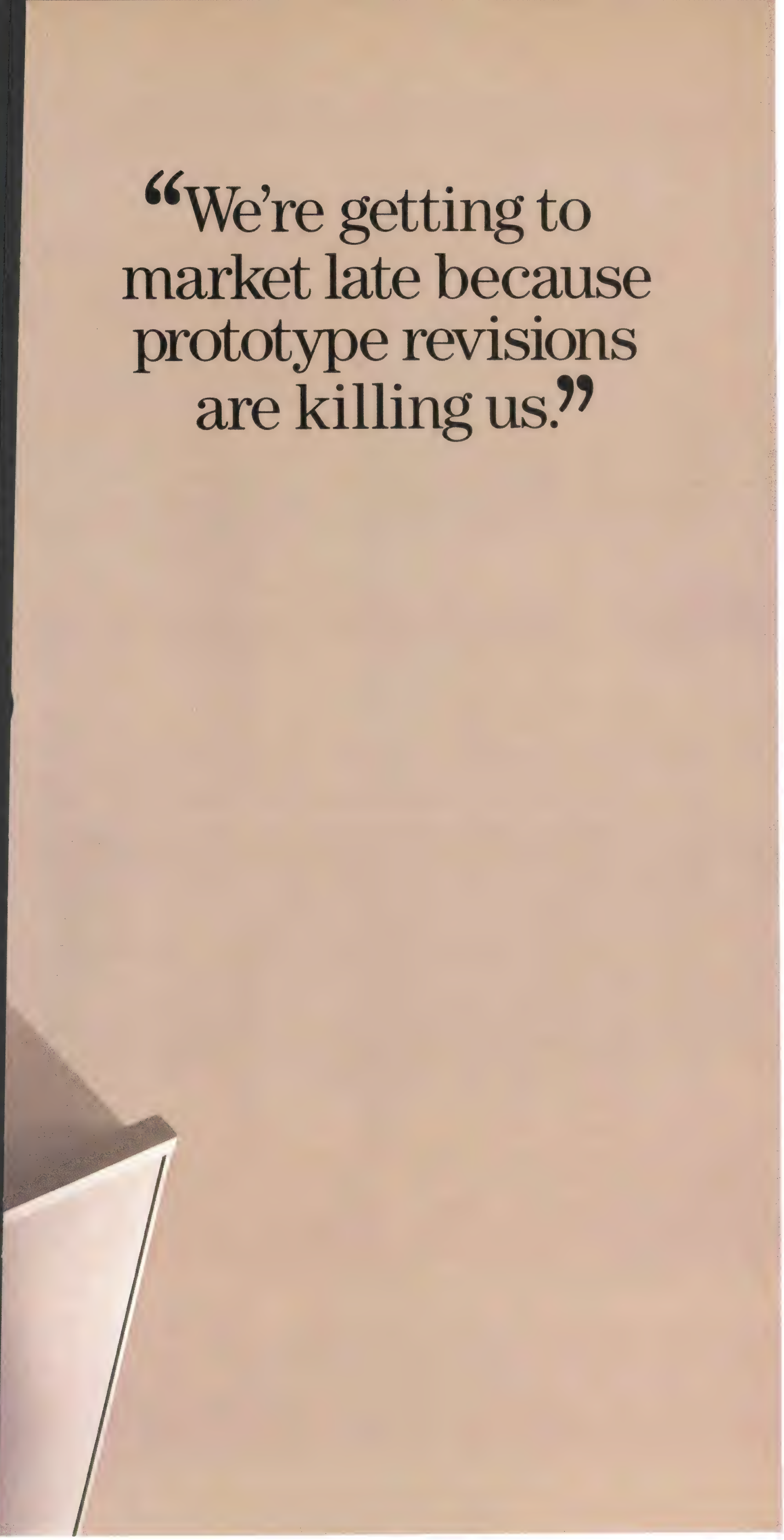

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We haven’t made prototype revisions a thing of the past…yet. But HP’s Electronic Design Automation (EDA) tools can catch most problems while designs are still in their infancy. Where you can fix them faster. At less cost.

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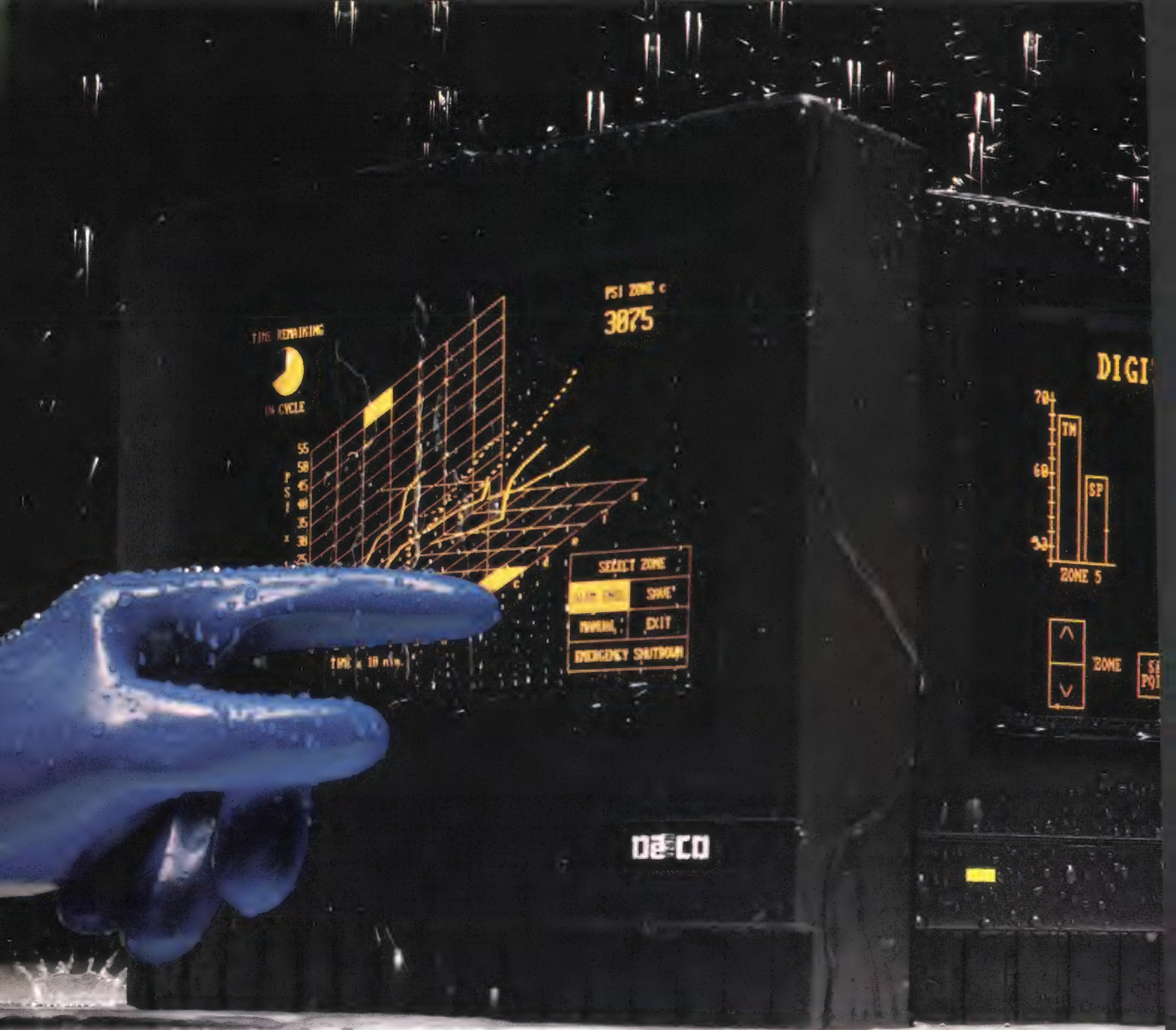
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At less than 12 pounds and only 3″ thin, they mount virtually anywhere with two bolts. Right on heavy machinery. Pedestal. Wall. Desk. Workbench. Anywhere.

The only thing about this family that isn't tough is using them. Touch screen software ease and flexibility makes configuring and reconfiguring fast and simple. For any industrial application.

So when you need friendly, interactive VT emulation, PC monitors or graphics terminals where ordinary terminals won't go, give us a call. We have a complete range of SealTouch solutions—including design-in modules without casing—one of which will be compatible with your system and the harsh realities of an industrial environment.

When the going is likely to get rough, this is the family to know. Call us. (415) 471-4700.

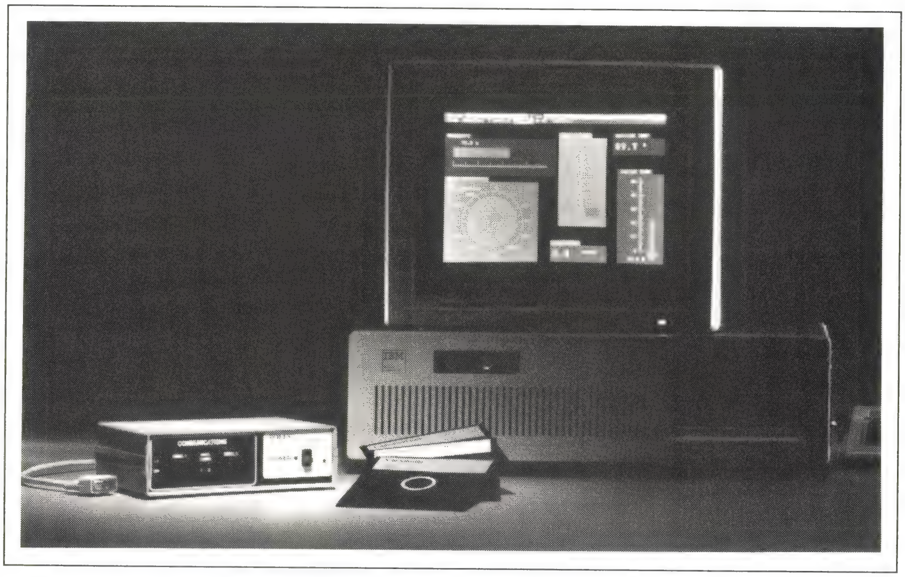
Digital Electronics Corporation, 31047 Genstar Road, Hayward, CA 94544-7831 (415) 471-4700

CIRCLE NO 133

ACQUISITION SYSTEM

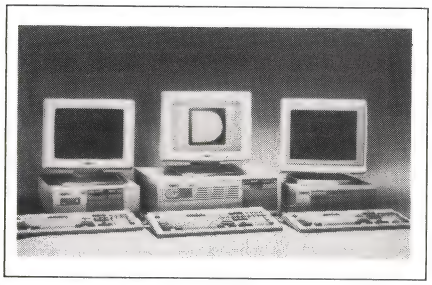
- *Accepts analog and digital data for the IBM PC family*
- *Contains a μP and SRAM for data logging*

The Solus Personal Control Computer is a data-acquisition system for IBM PC, PC/XT, PC/AT, PS/2, and compatible computers. The stand-alone hardware connects to a PC host or a modem via an RS-232C port at communication rates from 300 to 9600 bps. An additional RS-232C port lets you daisy-chain multiple units. The hardware contains a CMOS μP, 8k bytes of SRAM for an operating system, and 24k bytes of SRAM for data logging. The CPU has a real-time clock with battery backup. The system can accommodate 15 digital inputs, one of which can interrupt the μP. The system also has 14 single-ended analog inputs, which can accept bipolar or unipolar inputs within a variety of voltage ranges. The unit provides 1X, 2X, 5X, and 10X gain ranges and uses a 10-bit ADC for data conversion. You power the unit from a 110V ac to 12V dc adapter or from a 12V car battery. The software consists of a menu-driven graphics package that runs on a PC having at least 256k bytes of memory and a graphics adapter card. Each hardware unit, $895; software, $595.



TMI Inc, 4000 Kruse Way Pl, Bldg 2-120, Lake Oswego, OR 97035. Phone (800) 247-5712; in OR, (503) 635-3966. FAX 503-635-3004.

Circle No 366



WORKSTATIONS

- *Operate with IBM System/3X and AS/400 systems*
- *Can also operate as PCs running MS-DOS*

The company's three computer models, the 5030, 5053, and 5070, can function as PCs or as workstations for the IBM System/3X and AS/400 computer systems. For workstation performance, you have the option of installing the company's terminal emulation board. The top performer, the 5070, features a 16-MHz 80386 μP, 2M bytes of RAM, an EGA adapter card for both monochrome and color monitors, two RS-232C ports, a parallel port, five IBM PC/AT- and two PC/XT-compatible expansion slots, and a 32-bit expansion slot for additional RAM. The 5053 features an 8/12-MHz 80286 μP, 1M byte of RAM expandable to 16M bytes, and a floppy-disk controller to support as many as two 5¼-in. or 3½-in. drives. The 5030 features an 8/9.6-MHz 8086 μP, 640k bytes of RAM, one RS-232C port, and can accommodate two 3½-in. and one 5¼-in. half-height disk drives. 5070, from $2795; 5053, from $1579; 5030, from $899.

Decision Data Computer Corp, 100 Witmer Rd, Horsham, PA 19044. Phone (800) 523-5357.

Circle No 367

CPU CARD

- *Suitable for use in multiprocessor VME Bus systems*
- *Has a quad-bus architecture to maximize throughput*

To maximize processing throughput and data-block transfer rates, the TSVME123 VME Bus CPU card has four separate onboard buses that can be accessed by its 16-MHz 68020 μP and a proprietary DMA controller. The 68020 executes instructions from 512k bytes of zero-wait-state local memory while data is being transferred between the VME Bus and the board's 1M byte of multiport RAM. Special circuitry to speed up write cycles to this RAM minimizes the contention time when the RAM is simultaneously accessed via more than one of its ports, and the DMA controller utilizes a FIFO buffer to improve the

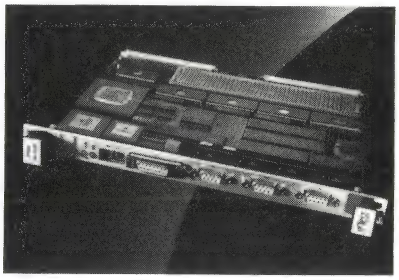
VME Bus bandwidth. VME Bus burst-mode data-transfer rates can exceed 20M bytes/sec. An extension bus, which can sustain data-transfer rates as high as 6M bytes/sec, allows the board to access additional high-speed memory. The TS-VME123 mailbox interrupts and bus interrupter make it suitable for use in multiprocessor systems. The board is supplied with a debug monitor and self-test firmware, and software support includes the pSOS and OS-9 operating systems. Approximately Fr 45,000.

Themis, 29 Ave de la Baltique, ZA de Courtaboeuf, 91953 Les Ulis Cedex, France. Phone (1) 69861525. TLX 603347. FAX 1-64464550.

Circle No 368

Themis Computer, 6681 Owens Dr, Pleasanton, CA 94566. Phone (415) 734-0870. FAX 415-734-0872.

Circle No 369



CPU BOARD

- *Runs a 68030 µP and 68882 math coprocessor*
- *Includes a real-time kernel that links to Unix or MS-DOS*

The CPU30, a CPU board for VME Bus systems, is based on a 20- or 25-MHz 68030 µP and a 68882 floating-point coprocessor. Utilizing the company's proprietary VME Bus interface chip, the board features DMA capabilities at data-transfer rates as high as 20M bytes/sec, eight mailbox interrupts, and the capability of generating broadcast messages on the VME Bus. The board has a SCSI interface, an SA460 floppy-disk interface, an 8-bit parallel I/O port with handshaking capabilities, and four serial I/O ports. You can configure the serial I/O ports to operate with RS-232C, RS-422, or RS-485 protocols, using plug-in modules that are supplied with the board. The board has 4M bytes of parity-protected dynamic RAM that's ported to the 68030 µP and the VME Bus. You can expand onboard memory to 16M bytes when 4M-bit DRAMs become available. The board also has 32k bytes of battery-backed static RAM, a real-time clock, two 24-bit timers, and one 8-bit timer. It is supplied with the company's VMEPROM firmware which includes a real-time kernel, a monitor, and a file manager. This firmware allows you to link the board's operating system into Unix or MS-DOS systems. Op-

tions include a plug-in Ethernet interface. DM 10,000 to DM 15,000.

Force Computers GmbH, Daimlerstrasse 9, 8012 Ottobrunn/Munich, West Germany. Phone (089) 600910. TLX 524190. FAX 089-609-7793.

Circle No 370

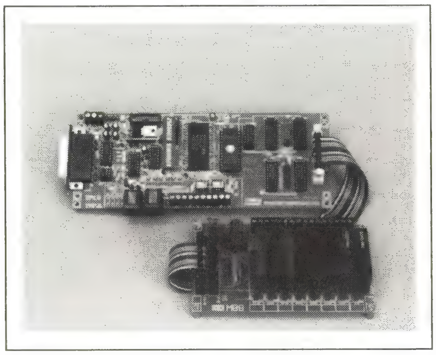
Force Computers Inc, 3165 Winchester Blvd, Campbell, CA 95008. Phone (408) 354-3410. TLX 172465. FAX 408-395-7718.

Circle No 371

ACQUISITION MODULE

- *Controls 16 input/output points and one RS-232C device*
- *Communicates with host more than 1 mile away*

The DM16 remote data-acquisition and control unit resides in an industrial-automation or process-control device. It contains a μP for controlling as many as 16 I/O points and



one RS-232C- or RS-422-compatible device. The module communicates with a host, which can be located more than 1 mile away, via the company's "4×4 Link" network. One link consists of either two twisted-pair wires or a modular telephone cable, which can support as many as 40 units. A fully configured network can support as many as 1600 RS-232C devices and 25,000 I/O points. The network can communicate at rates as high as 115,200 baud with different devices operating at different baud rates. The DM16 units connect to one COM port on the host computer. Optical isolation is available as an option. \$199 to \$294.

Connecticut microComputer, Box 186, Brookfield, CT 06804. Phone (800) 426-2872; in CT, (203) 354-9395. FAX 203-355-8258.

Circle No 372

WORM DRIVE

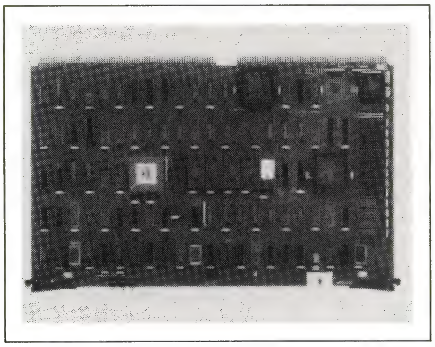
- *Stores 400M bytes of data in a 5¼-in. subsystem*
- *Average access time of 135 msec*

The LaserBank 400 WORM (write once/read many) disk-drive system is a stand-alone system in a 5¼-in. form factor that communicates with a host via a resident SCSI adapter. The unit has an average access time of 135 msec and can operate with an IBM PC, PC/XT, PC/AT, PS/2, or a compatible computer. It can

also operate with Sun workstations, MassComp computers, and the AT&T 6386 microcomputer. You can run the unit with five operating systems: DOS 3.1 or higher; SCO Xenix 286 2.21 or higher; SCO Xenix 386 2.3 or higher; Berkeley Systems' Unix BSD; and AT&T's Unix System V. The unit's DOS interface makes the optical disk appear as a Winchester hard disk. The Xenix version treats the drive as a standard Xenix block device, permitting the user to create a file system on the optical disk. Its Opal software contains a library of applications that permits the programmer to directly access the optical disk within an application. $2995.

Micro Design International Inc, 6985 University Blvd, Winter Park, FL 32792. Phone (407) 677-8333. FAX 407-677-8465.

Circle No 373



SCSI ADAPTER

- *Has a 68020 μP*
- *Two DMA controllers support 12.5M-byte/sec transfer rates*

The Model PT-VBS420 SCSI host adapter for the Versabus utilizes a 68020 μP that supervises the SCSI activities and provides a 32-bit address and data path to the Versabus. The device also contains a Versabus/VME Bus slave-interface controller on a programmable ASIC chip. The board contains an RS-232C port that lets you configure the board using a menu-driven mode on a terminal. The board has two independent DMA controllers that support sustained data-transfer rates of more than 12.5M bytes/sec on the Versabus and more than 5M bytes/sec on the SCSI bus. In addition, the adapter features 1M byte of RAM, operation in the Versabus block mode, synchronous or asynchronous operation, and differential or single-ended SCSI bus drivers. The board comes with SCSI firmware that supports multithreaded SCSI operations. $1740 (100).

Performance Technologies Inc, 435 W Commercial St, East Rochester, NY 14445. Phone (716) 586-6727. TWX 650-293-8297. FAX 716-586-6707.

Circle No 374

GRAPHICS CONTROLLER

- *Uses TI's 34010 graphics µP and TIGA-340 software*
- *IBM PC/AT-compatible board drives 1280×1024-pixel monitors*

The Artist TI12 graphics controller card for the IBM PC/AT, Compaq 386, and compatible computers is available in either 16- or 256-color versions with optional add-on modules for memory expansion and single- or dual-screen VGA compatibility. The single-screen configuration requires a multiscan monitor in the range of 31 to 64 Hz. The board drives monitors with 1280×1024 noninterlaced pixels. The board uses TI's 32-bit 34010 graphics µP, which delivers 6 MIPS on the PC/AT bus and provides compatibility with TI's TIGA-340 graphical-interface software. These functions allow the board to run programs such as CADkey, Hoops 3D, Halo graphics tool kit, and RoboCAD. The controller also supports IBM's Professional Graphics Language command set. Included with the board is the choice of Artist GT drivers for AutoCAD release 10 or the company's driver for X-Windows version 11. 16-color version, $3995; 256-color version, $5995; add-on module, which converts 16 colors to 256 colors, $2000.

Control Systems, Box 64750, St Paul, MN 55113. Phone (612) 631-7800. TLX 756601.

Circle No 375

MULTIUSER BOARD

- *Provides 24 RS-232C ports for the IBM PC/AT bus*
- *Operates with PCs running Unix and Xenix*

The Megaport serial-communications controller board for the IBM PC/AT bus provides 24 RS-232C ports for multiuser operating systems such as Unix, Xenix, Concurrent DOS, VM/386, and Pick. Each board occupies one PC/AT slot and controls communications for 24 simultaneous full-duplex asynchronous links operating at 38,400 bps. You can install as many as eight boards in a PC, providing 192 communications links. Using the company's ASIC chip set called the Intelligent Communications Processor, the board controls the communications and offloads the tasks from the host. The board is compatible with the company's line of wiring accessories, which lets you connect terminals, printers, modems, and PCs to the board. $1695.

Equinox Systems Inc, 14260 SW 119 Ave, Miami, FL 33186. Phone (305) 255-3500. FAX 305-253-0003. TLX 153893.

Circle No 376

SIMPSON PRO SERIES FUNCTION GENERATORS.
IT'S TIME TO WAVE BYE TO ALL OTHERS.

If you're looking for a sweep/function generator that'll create complex analog signals, Simpson now makes your decision anything but complex.

Introducing the high precision, *Professional Series* lineup of sweep/function generators from Simpson.

Designed to deliver precise digital frequency control, the top of the line model features standard output functions to 13MHz. A built-in 6-digit frequency counter sets the speed of the output, while allowing you to measure external signals up to 80MHz.

You'll also be impressed with the exceptional lin/log sweep range; and the auxiliary, sine,

square and triangle generator that lets you direct internal control of AM and FM waveshapes. All this without the need of a second generator.

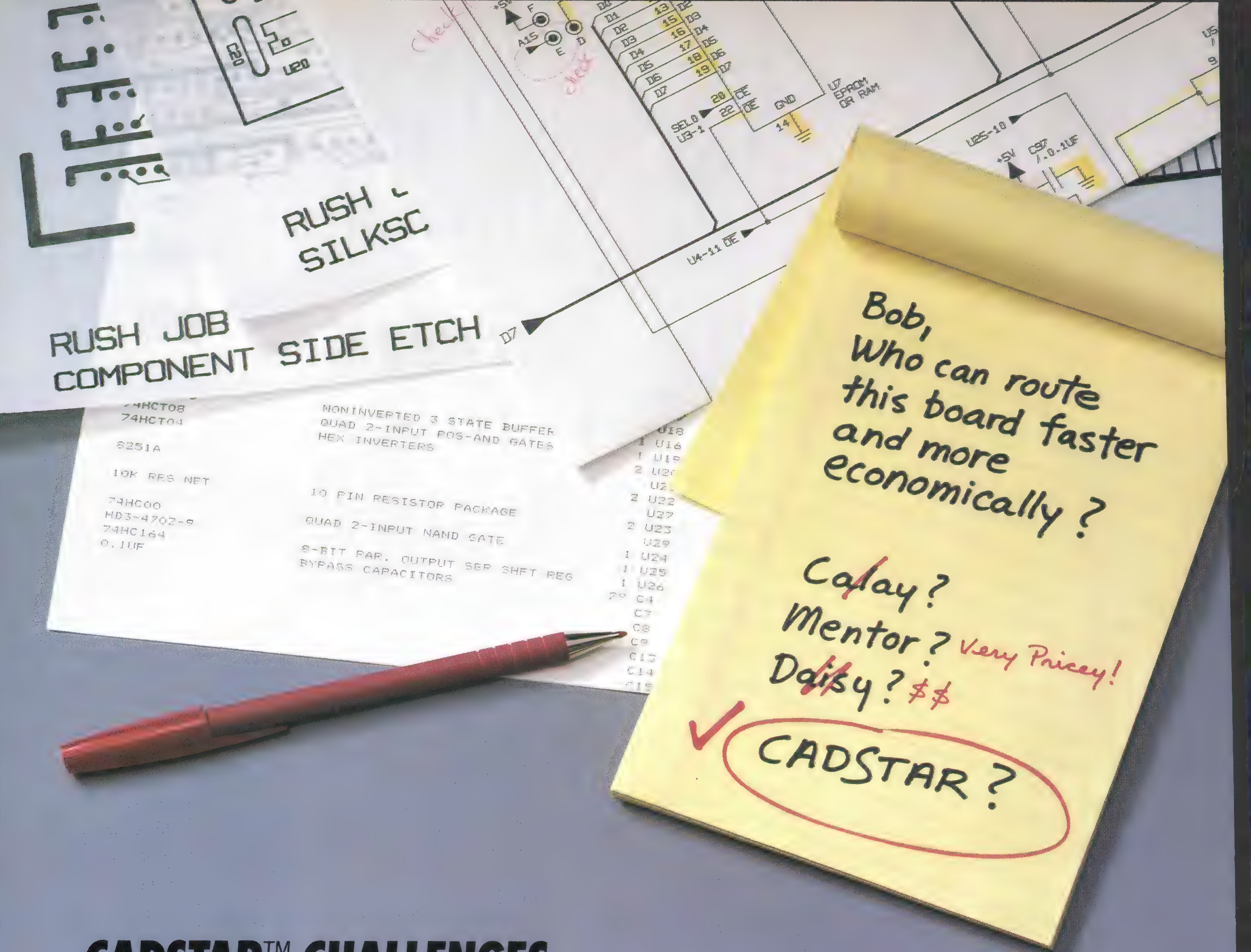
No matter which *Professional Series* model you choose—from 5MHz to 13MHz—you can be sure that if it's made by Simpson, it has the reliability, accuracy and precision that are synonomous with the name.

We call that a clean sweep. Once you buy one, you'll call it a sweet deal.

Simpson Professional Series products are made in USA.

simpson

Simpson Electric Company 853 Dundee Ave., Elgin, Illinois 60120-3090 312/697-2260 FAX: 312/697-2272



CADSTAR™ CHALLENGES WORKSTATION ROUTERS...

...ON SPEED!

The CADSTAR 386 Advanced Router is the fastest, most economically priced PC-based 32-bit gridless router in the business. And we challenge the competition to match its results.

In a recent benchmark, CADSTAR's 386 router proved superior in speed and performance. It routed in one-fifth of the time that it took the competition. And the results were completely manufacturable. Features like rip up, retry, shove aside, and re-entrant routing make board layout fast. And ECO's have never been easier.

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CADSTAR's PC-based Design and Layout Software is the best mid-range CAD system in the industry. It enables you to perform 95 percent of all the interactive and automatic capabilities of high-end workstations. As a result, you'll be able to handle today's most sophisticated boards—high-density dual in-line boards and multilayer, surface-mount designs. CADSTAR is easy to learn and fully supported with our hot-line service.

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CADSTAR meets the challenge. It combines the best in PCB CAD software with our CADSTAR Advanced 32-bit Gridless Router. Buy this package for a fraction of the cost of workstation systems. Or ask for CADSTAR PCB separately.

And CADSTAR is the only mid-range system that offers you a true migration path, from our low-end PC-based MAXI/PC system up to CADSTAR and from there to our high-end Visula™ engineering workstation.

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Telephone: 1-508-692-4900

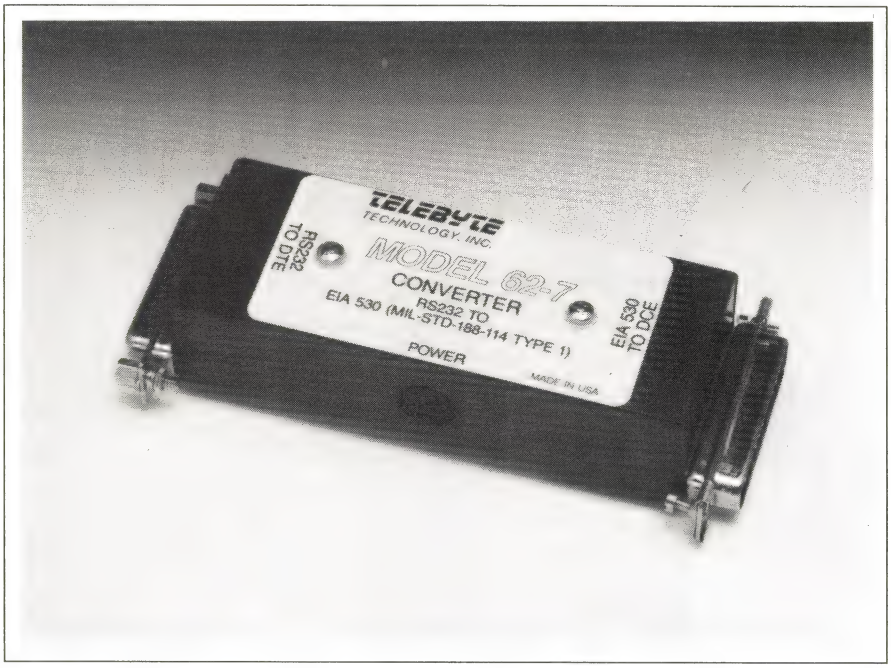
RACAL

COMPONENTS & POWER SUPPLIES

MINI CONVERTERS

- *Interface to DTE/DCE devices*
- *Handle differential or single-ended signals*

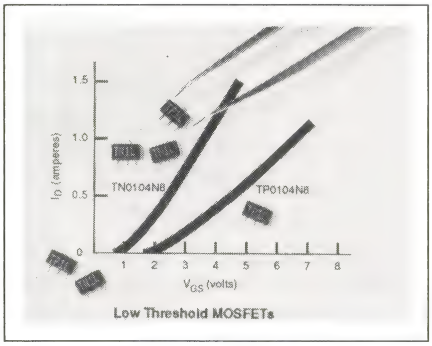
Model 62-7 and 62-8 stand-alone converters perform the conversion between RS-232C and MIL-STD-188-114 signals. The 62-7 RS-232C port interfaces with a DTE device, and the 62-8 interfaces with a DCE device. Each model provides conversion for the entire logical EIA-530 interface, including 10 category I circuits (differential signals) and three category II (single-ended signals) circuits. The electrical interface of the EIA-530 port fully complies with MIL-STD-188-114 Type 1, which is differential and bipolar. Both units can pass data at rates as high as 150 kHz. The mechanical interface of the 62-7 features a male DB-25 connector on the MIL-STD port and a female DB-25 connector on the RS-232C port. Connector sexes are reversed on the 62-8.



Model 62-4PS, a wall-mounted power supply, is available for powering the interface modules. Models 62-7 and 62-8, $160; Model 62-4PS, $32.

Telebyte Technology Inc, 270 E Pulaski Rd, Greenlawn, NY 11740. Phone (800) 835-3298; in NY, (516) 423-3232. FAX 516-385-8184.

Circle No 381



POWER MOSFETS

- *Available in surface-mount package*
- *Feature a low threshold voltage*

The TN0104N8 is an N-channel low threshold device, and the TP-0104N8 is a P-channel complementary version. Both are available in an SOT-89 surface-mount package. Minimum drain-to-source breakdown voltage equals 40V for both devices. The maximum on-resistance is 2Ω for the N-channel device and 4Ω for the P-channel unit. The on-resistance is guaranteed at gate-to-source voltages of 5 and 10V to ensure good performance with logic-level drive voltages. The N- and P-channel MOSFETs have a gate threshold voltage of 1.6 and 2.4V max, respectively. TN0104N8, $0.49; TP0104N8, $0.56 (1000).

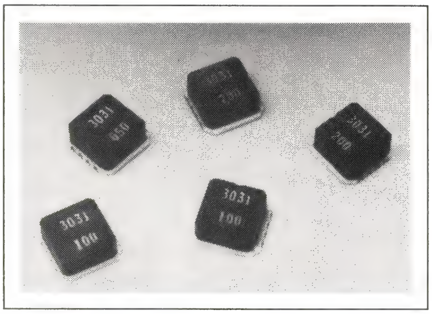
Supertex Inc, Box 3607, Sunnyvale, CA 94088. Phone (408) 744-0100. FAX 408-734-5247.

Circle No 382

ACCELEROMETER

- *Housed in a surface-mount package*
- *Operates from 5V*

Housed in a surface-mount package, the Model 3031 solid-state accelerometer consists of a micromachined



silicon mass suspended by multiple beams to a silicon frame. Piezoresistors located in the beams change their resistance as the motion of the suspended mass changes the strain in the beams. Requiring only a single 5V supply for operation, the 3031 features full-scale acceleration ranges of ±2 to ±500g. Silicon caps on the top and bottom of the device are added to provide overrange stops and built-in damping results in a wide dc to 2500-Hz bandwidth.

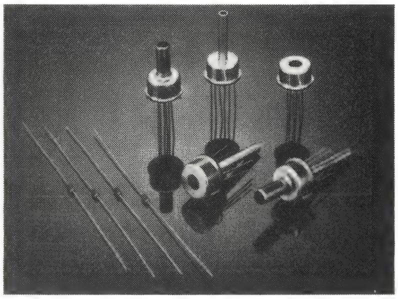
The 3031 has a 0.707 damping factor; ±0.2% of span linearity, including hysteresis; and a −40 to +125°C operating range. $5 (OEM qty).

IC Sensors Inc, 1701 McCarthy Blvd, Milpitas, CA 95035. Phone (408) 432-1800.

Circle No 383

TRANSDUCERS

- *Provide ±0.05% accuracy*
- *Available in gauge, absolute, and differential versions*



Series 1840 pressure transducers employ a solid-state silicon diaphragm to provide high measurement accuracy and minimize hysteresis. The devices are available in four best-fit straight-line accuracy ranges: ±0.05, ±0.125, ±0.25, and ±0.5%. Seven models cover a full-scale pressure range of 5 to 100 psi in gauge, absolute, or differential versions. The span output is 75 to 150 mV dc. The transducers operate with a regulated 10V dc or 1.5 mA constant current-excitation source. Metal connectors are provided for the pressure and electrical ports. $10 (500).

Foxboro/ICT Inc, 199 River Oaks Parkway, San Jose, CA 95134. Phone (408) 432-1010.

Circle No 384

LED DISPLAYS

- *Offer 3-color capability*
- *Available in two matrix sizes*

LN Series LED dot-matrix displays can display red, green, or amber colors. They are available in 16×16 and 24×24 matrix sizes. You can stack the displays vertically or horizontally to satisfy small- or large-screen applications involving the display of characters, symbols, or graphics. Each unit consists of a display section and a drive-circuit section. A built-in RAM allows the LN units to easily interface with a personal computer. The displays have a wide 2- to 20-MHz speed range, 1000-lux luminosity, and operate from a 5V drive source. Duty cycles equal 1/16 and 1/24 for the 16×16 and 24×24 units, respectively. $160 (100).

Panasonic Industrial Co, 2 Panasonic Way, Secaucus, NJ 07094. Phone (201) 348-5268.

Circle No 385

SERVO AMPLIFIER

- *Develops a 4.8-kW output*
- *Has 98% efficiency*

The Model 244-1 servo amplifier develops a 4.8-kW (±160V at ±30A) continuous output. Peak current capability equals 44A to accommodate motor acceleration and reversal tasks. High-efficiency PWM circuitry achieves 76W dissipation at full power output—98% efficiency. The 22-kHz switching frequency helps to achieve a 300-Hz bandwidth. Because of the low dissipation, you can cool the amplifier using a heat sink that measures only 6.5×9×2.1 in. $579.

Copley Controls Corp, 375 Elliot St, Newton, MA 02164. Phone (617) 965-2410. FAX 617-965-7315. TLX 285975.

Circle No 386

CHASSIS

- *Provides a ruggedized chassis for industrial IBM PCs*
- *Accepts as many as three disk drives*

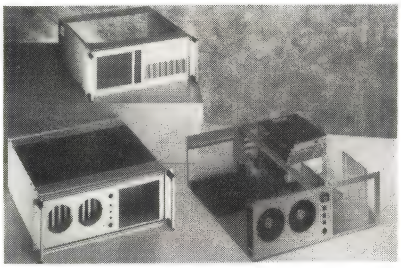
The IBM PC/XT or PC/AT Microrack provides you with an anodized aluminum chassis into which you can build a ruggedized PC. The unit comprises a 19-in. subrack and an enclosure that's 4U high and 390 mm deep. The subrack slides into the enclosure from either the front or the rear, and the complete unit mounts in standard 19-in. racks. It accepts the company's IBM backplane or 8-slot Mini-AT or -XT mother boards, and as many as three 5¼-in. slim-line disk drives. Cutouts at the rear of the unit allow you to mount four 25-way D connectors and the rear panels of expansion boards. The choice of two front panels both provide for two cooling fans, a keyswitch, indicator lamps, and a keyboard connector, as well as a cutout for the disk drives. Options include a choice of three power supplies. £435.

Bicc-Vero Electronics Ltd, Electron Way, Chandlers Ford, Eastleigh, Hampshire SO5 3ZR, UK. TLX 477984. FAX 0703-265126.

Circle No 387

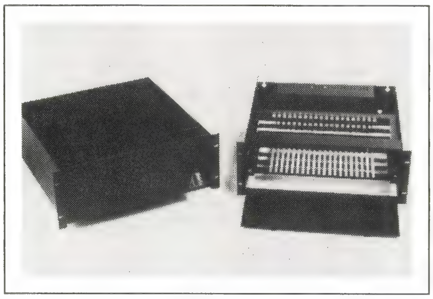
Bicc-Vero Electronics Inc, 1000 Sherman Ave, Hamden, CT 06514. Phone (203) 288-8001. TWX 510-227-8890.

Circle No 388



CARD CAGE

- *Available with 10 mother-board options*
- *Choice of power supplies*



The SC(X) STD Bus-type card cage is equipped with front access doors that make the card cage suitable for applications where access to the cards should be limited. Ten basic mother-board options are available, and the card design allows you to use multiple mother boards. The cage features ample room between the front access door and the cards to provide for cable turning clearance. Six switching power-supply options match the mother-board and card-population requirements. Top and bottom pan covers keep foreign objects away from the cards to reduce damage to the cage. The SC(X) can be rack- or table-mounted. $550.

Matrix Corp, 1203 New Hope Rd, Raleigh, NC 27610. Phone (919) 833-2000. FAX 919-833-2550.

Circle No 389

WIRING PEN

- *Traces dry in minutes*
- *Draws traces as narrow as 1/16 of an inch*

The Circuit Works pen provides a convenient means of making solderable terminations and traces on pc boards. The device incorporates a valved tip that allows users to smoothly apply the liquid silver conductor. Normal writing pressure opens the pen tip and the liquid silver flows easily. When not in use, the spring loaded tip closes to prevent drying problems. The pen can draw traces as narrow as 1/16 of an inch. The pen comes with enough conductor to make 150 feet of traces. The ink dries in minutes at room temperature and is more conductive than solder, having resistivity in the 0.03- to 0.05-Ω^2/mil

Dual Channel Filter - 1/2 Rack - 115 dB/Octave Performance

Compare the difference.
9002 performance features:

- **Choice of lowpass or highpass configurations**
- **Choice of 8-pole functions Butterworth , Bessel, elliptic and constant delay**
- **Size - 3 1/2"h x 8 1/2"w x 15"d**
- **3 1/2 digit frequency resolution from 0.1 Hz to102.4 kHz**
- **Pre/Post filter gain from +1 to +13.75 in 0.05 steps**
- **Keypad or IEEE-488 Bus programmable**
- **Gain/Phase matched filters**
- **Single ended or differential input**
- **AC or DC coupled inputs/outputs**
- **One price - $2,495.00 for all models**

The 9002 is small, only a half rack in width. But its size has nothing to do with performance. Each of the two channels is continuously tunable, without range switching. With a resolution of 3 1/2 digits, the 9002 is programmable from the front panel or the rear computer interface.

The user can store up to eight configurations on each of the two mix and match active filter channels and the eight configurations have up to six preset table parameters each. The 9002 battery-backed RAM will store filter configurations for up to five years. Any of a broad selection of channel filters can occupy either channel of the 9002. In addition, a lowpass and highpass filter can be cascaded to create a bandpass filter.

If one 9002 isn't enough, we can sell you a kit that allows you to install two 9002s side by side, in one standard 19" rack space.

Well, there you have it. The 9002 proves that good things come in small packages.

Need more information? Call us today at **508-374-0761** or contact us at 25 Locust Street, Haverhill, MA 01832. Our fax number is 508-521-1839.

FREQUENCY DEVICES™
The Active Filter People

range. Hand soldering is not recommended, but the traces are compatible with wave-soldering operations. $10.95.

Planned Products, 21105 Santa Cruz Hwy, Los Gatos, CA 95030. Phone (408) 353-4251. FAX 408-354-4818.

Circle No 390

POWER SUPPLIES

- *Operate at 200 kHz*
- *Provide 800W outputs*

The LLS Series power supplies are available in 20 models that provide outputs of as much as 1200V, 100A, or 800W. They have a 200-kHz switching frequency. You can control supply output from the front panel by slewing up or down via a pushbutton switch, by using the Standby mode to toggle between 0V and the desired setting, or by direct keyboard entry of the required values. The supplies can be remotely programmed. The programming constant is user selectable from 200 to 1000Ω/V. All models are designed for constant voltage/current operation at user-selectable inputs of 110 or 220V ac. Standard features include remote on/off, remote sense, and adjustable overvoltage protection. From $550.

Lambda Electronics, 515 Broad Hollow Rd, Melville, NY 11747. Phone (516) 694-4200.

Circle No 391

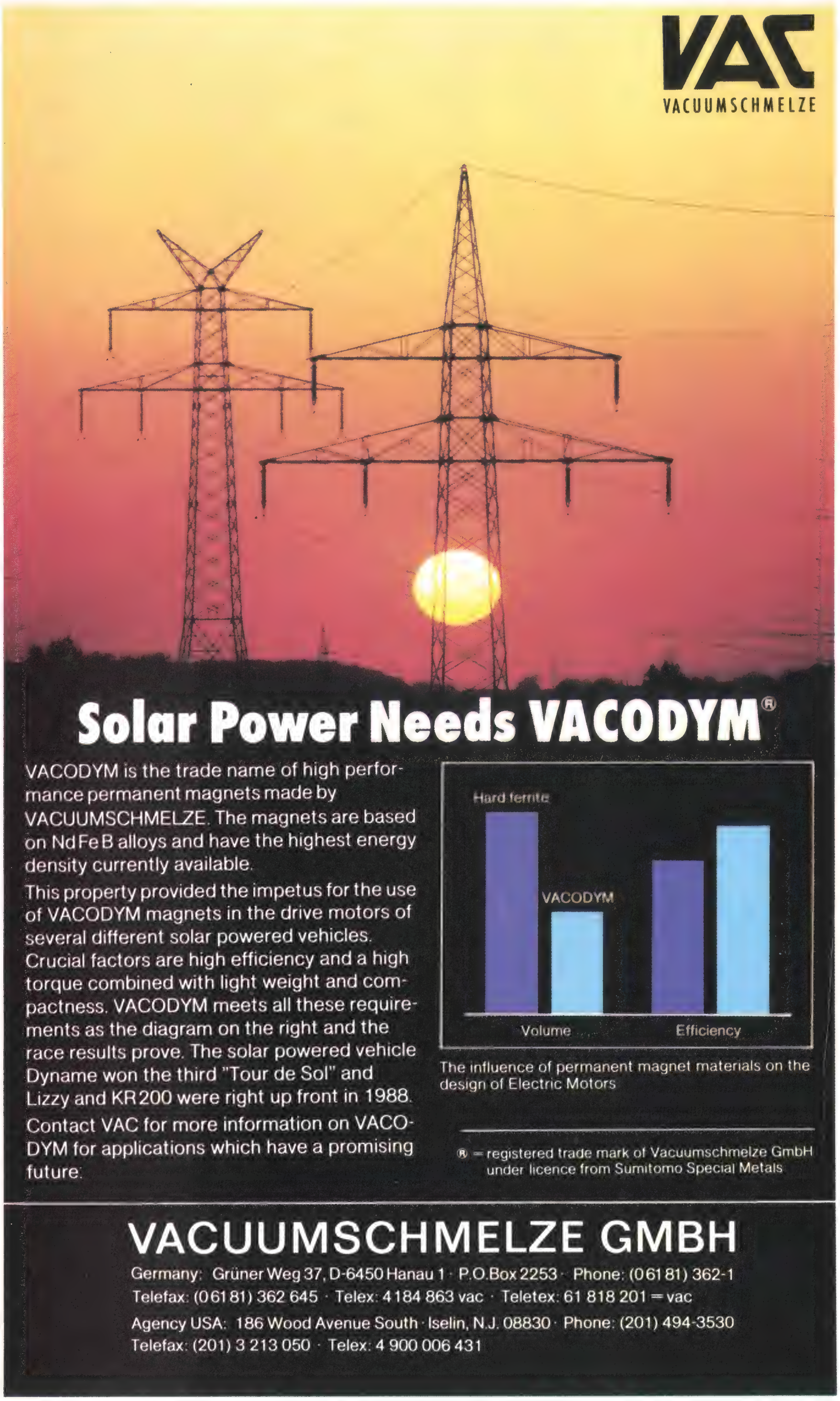
CRT SUPPLIES

- *Suitable for driving monochrome or color displays*
- *Optional remote-control input*

L- and M-series CRT power supplies are available with positive or negative outputs in the range 1 to 30 kV; an optional first anode output is available, if required. All the outputs are protected against short circuits. The supplies require a 24V dc input. L-series units have an output ripple of 500 ppm maximum, and M-series supplies have an output ripple of 50 ppm. The M-series supplies also have a remote control option that allows you to control the output voltage with a 0 to 10V analog input. Linearity between the control input and the output is ±1%. An optional adapter allows you to power the supplies from a line input. The series is available in commercial and military grade versions. L-series, £150 to £200; M-series, £190 to £340.

Wallis Hivolt Ltd, Dominion Way, Worthing, West Sussex BN14 8NW, UK. Phone (0903) 211241. FAX 0903-208017.

Circle No 392



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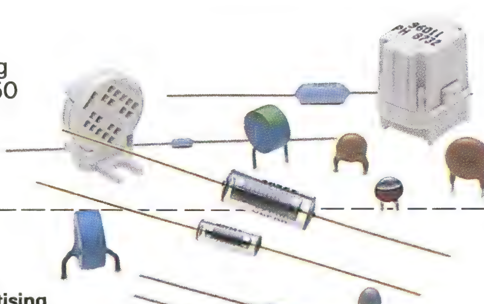

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Riviera Beach, FL 33404

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- ☐ Leaded Resistor/Capacitor Data Book
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Firm/Dept./Div. ____________________

Address/MS ____________________

City/State/Zip ____________________ Phone (   ) ____________________

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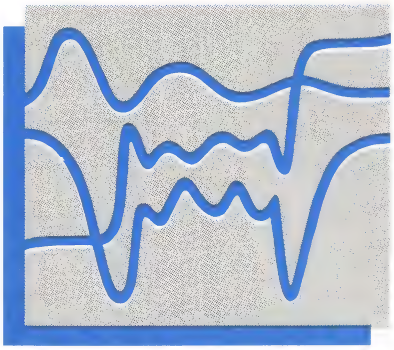
HSPICE



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CAE & SOFTWARE DEVELOPMENT TOOLS

STATISTICAL LIBRARY

- *Lets you insert statistical probabilities into component models*
- *Provides interparameter correlations*

The Monte Carlo analysis package, an enhancement to the vendor's Saber simulator, allows you to perform studies of part- and system-sensitivity and design manufacturability. The analysis package provides statistical values for the performance variances of models in the library; the statistical modeling package lets you insert standard probability-distribution functions into your own models or pass these functions into an existing model as a parameter. You can correlate parameter and part information in the circuit so that only meaningful part variations and permutations occur in the simulation. The statistical modeling package is free for current Saber users. Analysis package, from $5000.

Analogy Inc, 9205 SW Gemini Drive, Beaverton, OR 97005. Phone (503) 626-9700.

Circle No 396

RISC µP TOOL SET

- *Cross-development tool for Motorola 88000 RISC µP*
- *Runs on VAX, Sun-3, and Macintosh II host computers*

Oasys 88K software-development tools run on VAX, Sun-3, Macintosh II, and Motorola VME Delta host systems and allow you to develop and debug software for systems based on Motorola's 88000 RISC µP family. The tool set consists of the optimizing C, Pascal, and Fortran native and cross-compilers from Green Hills Software (Glendale, CA); the native and cross-development assembler/linkers and symbolic debuggers from Oasys (Waltham, MA); and the proprietary 88000 simulator developed by Motorola. This simulator lets you create the entire target 88000 system in software on the host computer and eliminates the need for an in-circuit emulator. Macintosh version, $4000; Sun-3 version, $9400; VAX version, $15,500.

Oasys Inc, 230 Second Ave, Waltham, MA 02154. Phone (617) 890-7889.

Circle No 397

VIDEO ANALYSIS TOOL

- *Works with a frame-grabber board*
- *Allows sophisticated image processing*

MV-JAVA is a menu-driven program that measures, processes, and analyzes video images. The program accepts live or frozen RS-170-compatible images from the vendor's MV1 frame-grabber board or digitized images previously stored on disk. You can enhance the captured images with features such as contrast enhancement; histogram equalization; median, smoothing, and convolution filters; background subtraction; zoom magnification; and touch-up painting. These features allow you to improve the image quality through noise reduction, edge definition, and the removal of unwanted objects. You can then perform a wide variety of measurements on the enhanced image; the program automatically transfers the measurements to a data worksheet, which lets you manipulate the data with user-defined equations and perform statistical analysis and plotting. The program runs on IBM PCs and compatibles. Software, $995; frame-grabber board, $1595.

MetraByte Corp, 440 Myles Standish Blvd, Taunton, MA 02780. Phone (508) 880-3000. FAX 508-880-0179.

Circle No 398

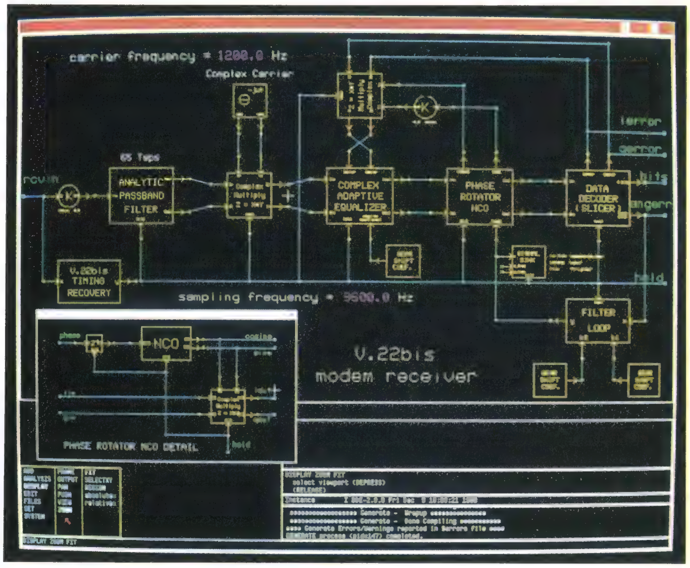
PLD DESIGN TOOL

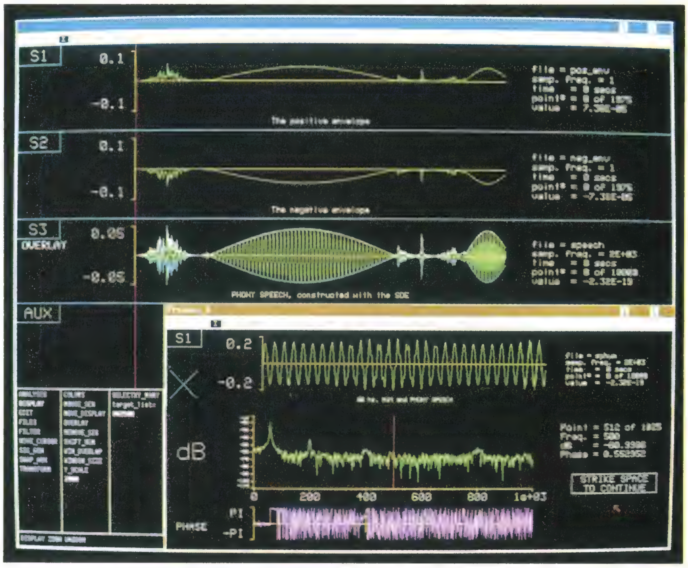
- *Lets you create a device-independent design description*
- *Fits your description into PLDs that meet your criteria*

PLDesigner allows you to describe your design using a combination of truth tables, Boolean equations, and a high-level procedural language. An expert system analyzes your description and fits it into one or more PLDs, suggesting the 10 physical devices that best meet your selection criteria. System 200 fits your design into one PLD, and System 300 can partition your design between as many as three PLDs. System 500 can partition your design between as many as 20 PLDs; it includes interfaces to the OrCAD, P-CAD, and FutureNet schematic-capture tools and a waveform editor for describing designs. All three tools run on IBM PC/ATs and compatibles. The System 4000 has more extensive capabilities and runs on Sun-3 workstations. System 200, $1950; System 300, $2950; System 500, $4500; System 4000, $9500.

Minc Inc, 1575 York Rd, Colorado Springs, CO 80918. Phone (719) 590-1155. FAX 719-594-4708.

Circle No 399





SCHEMATIC EDITOR

- *Libraries contain more than 6100 parts*
- *Lets you create more than 4000 sheets per design*

Version 3.20 of the OrCAD/SDT III provides major enhancements over previous releases of this widely used, PC-based schematic-capture tool. Libraries of Altera, Intel, and generic PLDs and libraries of parts for generating simulation models raise the number of unique parts to more than 6100. Net-list formats include AlteraADF and Intel ADF for EPLD development; and CASE, Hilo, Mentor Board Layout, and VSTModel for developing simulation models in the vendor's digital simulator. The incremental-annotation feature lets you update a design without changing the references, and the capacity has been increased from 300 to more than 4000 sheets per design. $495.

OrCAD Systems Corp, 1049 SW Baseline St, Suite 500, Hillsboro, OR 97123. Phone (503) 640-9488. FAX 503-640-6491.

Circle No 400

TEST SOFTWARE

- *Generates test programs for PLDs*
- *Runs on a PC*

The latest version of the PalSolve automatic test-generation software produces programs that can test gate-array logic (GAL) and erasable programmable logic devices (EPLDs) in addition to the programmable-array logic (PAL) for which this software was originally designed. Running on an IBM PC or compatible computer, the software allows you to generate ATE programs for PLDs by inputting only the fuse-link pattern and the generic type of the tested device. You can use it to generate test programs for many ATE and board-test systems, including Sentry S20 and MCT-2000 Series testers. For Sentry testers, the software produces a test program that includes fully functional ac and dc parametric tests in less than 10 minutes. The package includes an add-in board for the PC and cabling to connect the PC to an ATE system, and it is available as a front-end test-vector generator that produces functional test patterns for use with PLD programmers. Version with full parametric testing capability, approximately £15,000; front-end test-vector generator version, approximately £5,000.

MTL Microtechnology Ltd, Test House, Mill Lane, Alton, Hampshire GU34 2QG, UK. Phone (0420) 88022. TLX 858456. FAX 0420-87259.

Circle No 401

VHDL LIBRARY

- *Contains models of more than 4000 parts*
- *Works with vendor's VHDL simulation tool*

Logic Automation Inc (Beaverton, OR) has converted its SmartModels library to be compatible with the vendor's VantageSpreadsheet VHDL simulation tool. The library includes models of more than 4000 devices, including the MC68030 and Am29000 µPs, peripherals, PLDs, and memories. As Logic Automation adds new SmartModels to its library, these models will also be converted for use with VantageSpreadsheet. Single-workstation site license, $7000.

Vantage Analysis Systems Inc, 428-40 Christy St, Suite 201, Fremont, CA 94538. Phone (415) 659-0901. FAX 415-659-0129.

Circle No 402

MAC CROSS-COMPILERS

- *Cross-development packages for a Mac*
- *Include assemblers, HLL compilers, and source-level debuggers*

This family of program-development and debugging tools, formerly available only for workstations and IBM PC hosts, is now available for the Apple Macintosh. These tools let you develop and debug software for embedded systems that are based on the National Semiconductor 32000 µP family or the Motorola 6300, 6800, and 68000 µP families. C and Modula-2 cross-compiler packages, $2000 each; assemblers and source-level debuggers, $1000 each.

Introl Corp, 647 W Virginia St, Milwaukee, WI 53204. Phone (414) 276-2937. FAX 414-276-7026.

Circle No 403

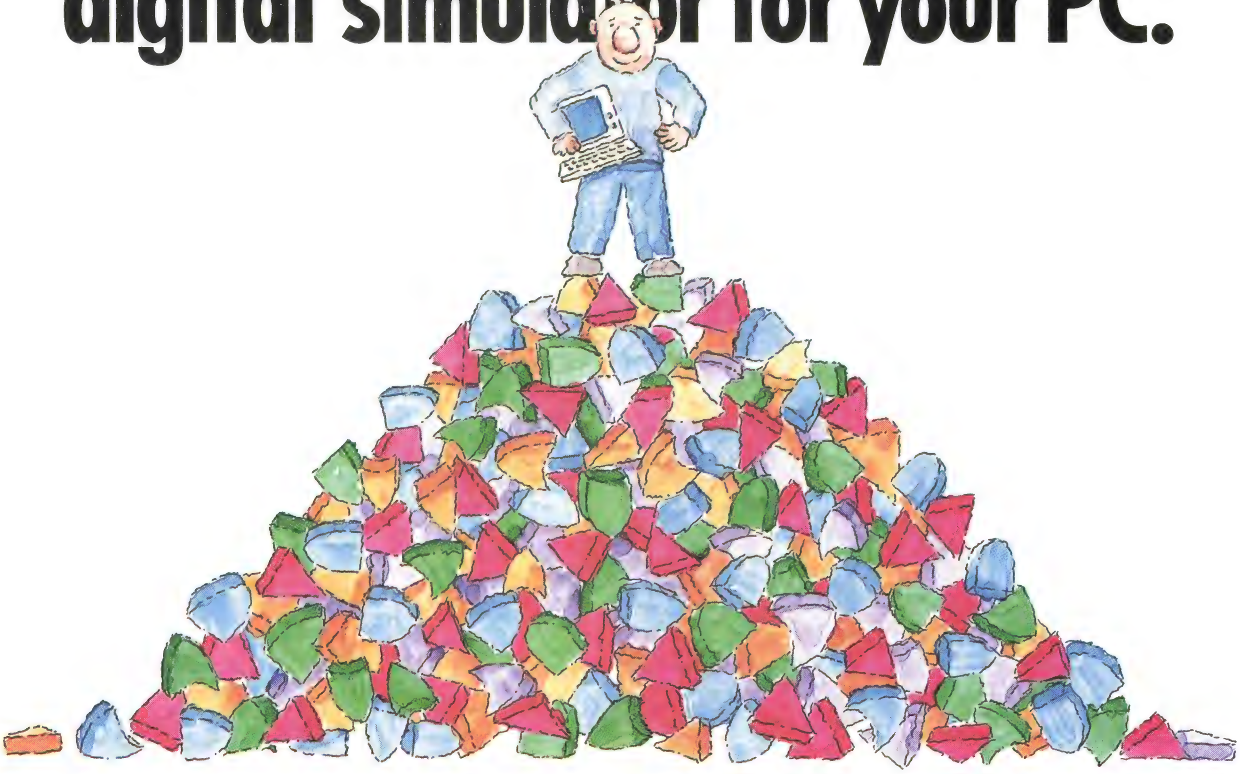
PARTS LISTER

- *Lets you build a simple or customized parts list*
- *Builds tables for IC power and ground connections*

The Enhanced Part List Utility lets you build either a simple parts list showing quantity, part name, and all location designators, or a customized list that contains additional information that you supply to meet your needs. The program generates a last-component-used table and a table for IC power and ground connections, and it can format these tables (or any ASCII text file) into a FutureNet area file. You can then load these area files directly into a Dash schematic and generate the tables for each individual sheet of a design or for an entire design of unlimited size. The program runs

MICRO-LOGIC II.™

The CAE tool with a 10,000-gate digital simulator for your PC.



Spectrum Software's MICRO-LOGIC II® puts you on top of the most complex logic design problems. With a powerful total capacity of 10,000 gates, MICRO-LOGIC II helps engineers tackle tough design and simulation problems right at their PCs.

MICRO-LOGIC II, which is based on our original MICRO-LOGIC software, is a field-proven, second-generation program. It has a high-speed event-driven simulator which is significantly faster than the earlier version.

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The program provides you with a top-notch interactive drawing and analysis environment. You can create logic diagrams of up to 64 pages with ease. The software features a sophisticated schematic editor with pan and zoom capabilities.

Shape Editor

A 200-type library of standard parts is at your fingertips. And for a new high in flexibility, a built-in shape editor lets you create unique or custom shapes.

MICRO-LOGIC II is available for the IBM® PC. It is CGA, EGA, and Hercules® compatible and costs only $895 complete. An evaluation version is available for $100. Call or write today for our free brochure and demo disk. We'd like to put you in touch with a top digital solution.

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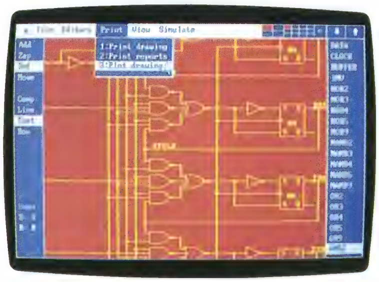

Schematic Editor

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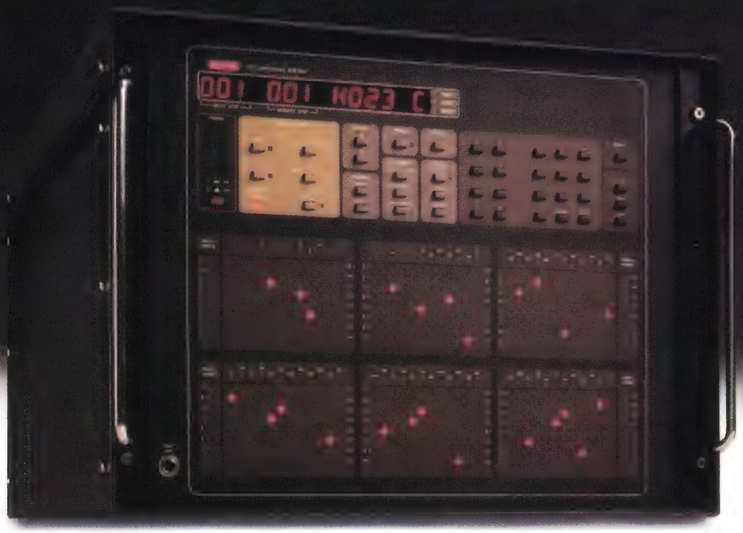
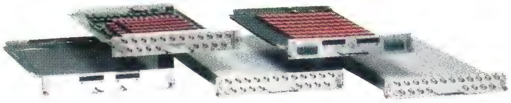
SWITCHING SOLUTIONS

for your ATE



Model 707 Switching Matrix—the heart of a superior ATE system—accepts up to 6 matrix cards.

It's in the cards. Keithley's Model 707 Switching Matrix accepts a full range of interchangeable switching cards, so you can custom-design your test system for the best performance. Optimize switching characteristics to specific signals for more reliable, repeatable test results.



Connect quick. The 707's built-in analog backplane conducts signals between cards and eliminates external cabling. Control up to 2880 relays from one IEEE-488 address for signals from 5µV to 200 VDC, and up to 30 MHz.

Point and program. Program your test interconnect quickly and easily with the optional light pen. Use the pen to toggle any relay state, verify the setup on the display, and record up to100 relay configurations—or transfer them to computer memory.

Call our Technical Support Hotline, **(800) 552-1115**, any time before 7:00 p.m. EST. Our Applications Engineers are available to help you configure your next switching system.

And be sure to ask for your free copy of Keithley's authoritative *Switching Handbook* and the *Model 707 Configuration Guide.*

The Model 707
Switching Matrix

KEITHLEY

CIRCLE NO 138

on IBM PCs, PS/2s and compatibles. $95.

CAD Utility Co, 21115 Devonshire St, Suite 318, Chatsworth, CA 91311. Phone (818) 594-1856.

Circle No 404

DIAGNOSTIC TOOL

- *Identifies and tests the hardware installed in a PC*
- *Can be used remotely from another PC*

CheckIt is a diagnostic software package that identifies the hardware and software installed in an IBM PC, PS/2, or compatible machine and tests for specific problems. You can select a total-system test, a test of one function, or any group of the available tests. Some of the tests measure actual system throughput; running these tests on different machines lets you determine which machine would perform best in graphics or spreadsheet use or as a network file server. The universal graphics-translator function allows the program to work with Hercules, CGA, EGA, VGA, and extended PS/2 CGA graphics adapter boards; this function can also emulate DEC VT52 and VT100, Televideo 920, and IBM 3101 terminals. You can upload and run CheckIt from a remote PC with the aid of Meridian's (Irvine, CA) Carbon Copy program; the test results appear on the remote PC and on the system under test. The bundled CheckIt/Carbon Copy package comes with Mace Vaccine (an antivirus protection) and costs $195.

TouchStone Software Corp, 909 Electric Avenue, Suite 207, Seal Beach, CA 90740. Phone (213) 598-7746. FAX 213-430-3829.

Circle No 405

AI LANGUAGE

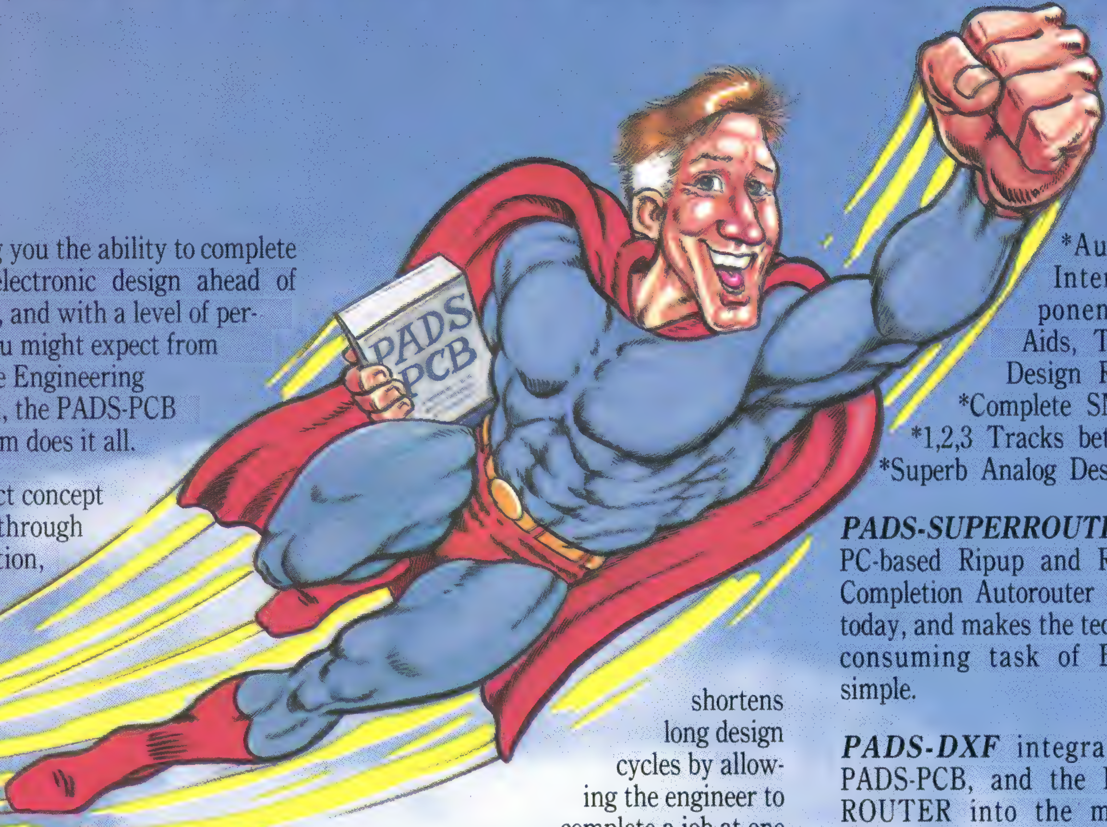
- *Combines algorithmic and rule-based programming*
- *Improved Rete match algorithm speeds rule selection*

OPS83 is a rule-based programming language for the development of artificial-intelligence software. Version 3.0 uses Rete II, an enhanced version of the industry-standard Rete match algorithm, to reduce the time it takes for the OPS83 compiler and run-time system to perform complex matching operations. Version 3.0's qselect() function selects rules from the conflict set, and the select() function implements either the LEX strategy or the MEA strategy for rule selection. You can specify the size of the matcher's hash tables, allowing you to make a tradeoff between the size and speed of your application. Also, you can write the main routine in any OPS83-compatible language, such as C or Fortran. Another enhancement allows you to specify each rule's priority, using an integer constant; the new conflict-resolution procedures give preference to the rule with the highest priority number. The enhancements yield a performance improvement that lets you develop real-time AI applications. Recompiling existing applications can increase overall execution speed by 33 to 300%; very complex operations will run 10 or more times faster. The compiler runs on various workstations and on IBM PCs and compatibles under MS-DOS and OS/2. From $1950.

Production Systems Technologies Inc, 5001 Baum Blvd, Pittsburgh, PA 15213. Phone (412) 683-4000.

Circle No 406

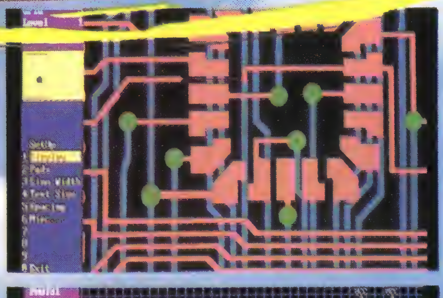
NEED SUPER-FAST DESIGN THRUPUT?

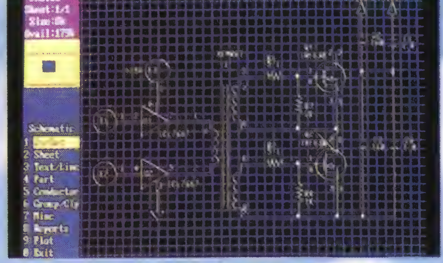


Giving you the ability to complete an electronic design ahead of time, and with a level of performance you might expect from an expensive Engineering Workstation, the PADS-PCB design system does it all.

From product concept and design, through implementation, PADS-PCB shortens long design cycles by allowing the engineer to complete a job at one station with features such as:

- **LOGIC CAPTURE**
- **PRINTED CIRCUIT BOARD DESIGN**
- **AUTOPLACEMENT**
- **100% RIP-UP & RE-ROUTE AUTOROUTING**
- **AUTO CHECKING**
- **AUTOCAD INTERFACE**





Utilizing a design-oriented database, ***PADS-CAE*** accesses all the sheets of a schematic simultaneously. Auto REF DES, Auto Gate Assignment and Data Checking across all sheets are also provided.

PADS-PCB is the most popular Printed Circuit Board Design System on the market and offers:

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CIRCLE NO 98

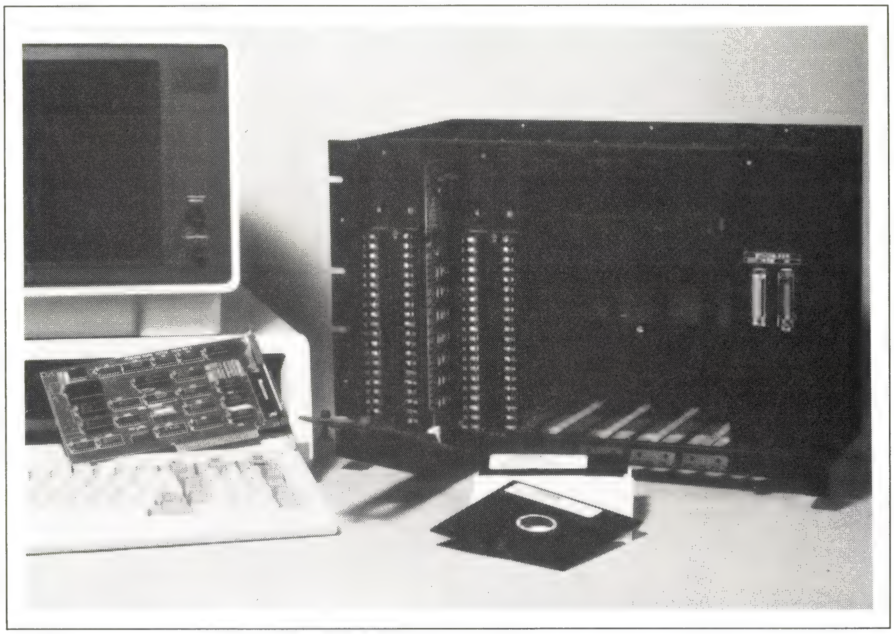
CAD
Software, Inc.
119 Russell Street
Suite #6
Littleton, MA 01460

TEST & MEASUREMENT INSTRUMENTS

MONITORING SYSTEM

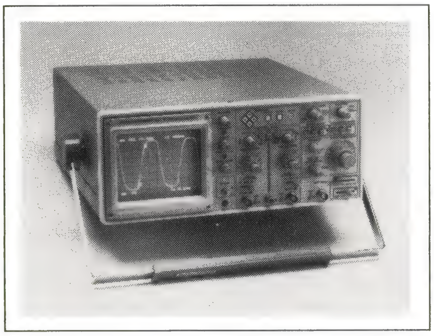
- *Compatible with IBM PC and PS/2 families*
- *Allows 3584 analog or 1024 digital I/O points per expansion slot*

The Workhorse system consists of a driver board that plugs into a slot on the bus of an IBM PC, PS/2 or compatible computer, and one or more ac-powered, rack-mountable chassis, each of which accommodates seven user-selected I/O cards. Via a 25-conductor cable, one driver card controls chassis that contain 3584 analog or 1024 digital I/O points. A 12.25×17.25×10.25-in. chassis accommodates 112 3A relay outputs, 112 analog inputs or 224 low-level digital I/O points. Data transfer between the computer and the chassis occurs at 500k bytes/sec under full handshake control. DOS-compatible device drivers simplify system programming; by calling these drivers from high-level-language programs, you can pass data to and from the I/O cards. From $2618.



Metrabyte Corp, 440 Myles Standish Blvd, Taunton, MA 02780. Phone (508) 880-3000. TLX 503989.

Circle No 410



ANALOG SCOPES

- *Provide onscreen readout of cursor measurements*
- *Simultaneously display two cursor measurements*

The 9202 is a 20-MHz-bandwidth analog scope and the 9204 is a 40-MHz-bandwidth unit. Both scopes have two vertical channels; "A" and "B" sweeps; and two onscreen numeric readouts of voltage, time, and frequency, each controlled by a pair of cursors (a reference cursor and a delta cursor). You can move the cursors individually or together. Cursor keys allow movement in eight directions at 45° intervals. Each scope is delivered with a pair of probes that you can switch from ×1 to ×10 attenuation or to ground. 9202, $865; 9204, $1095.

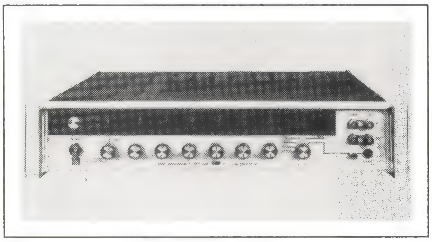
Beckman Industrial Corp, 3883 Ruffin Rd, San Diego, CA 92123. Phone (619) 495-3200. TLX 249031.

Circle No 411

DC CALIBRATOR

- *Provides known voltages and currents*
- *Offers 1-ppm resolution and 20-ppm errors*

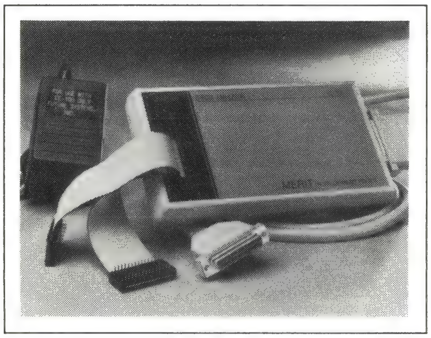
The Model 521 is a µP-based, IEEE-488-controlled, dc voltage/current calibrator. It transparently runs programs written for the vendor's earlier Models 520, 520/A and 501/J. The 3½-in.-high unit produces currents from 10 nA to 110



mA in two ranges, and voltage compliance in current-forcing mode is 100V. The instrument has three voltage-forcing ranges with 100-mA compliance. It can produce outputs from 100 nV to 100V and offers the option of an 1100V range. All ranges provide 1-ppm resolution and a "crowbar" zero. Within one year of calibration, voltage-forcing error is 20 ppm; current-forcing error is 50 ppm. $3150. Delivery, 60 days ARO.

Electronic Development Corp, 11 Hamlin St, Boston, MA 02127. Phone (617) 268-9696.

Circle No 412



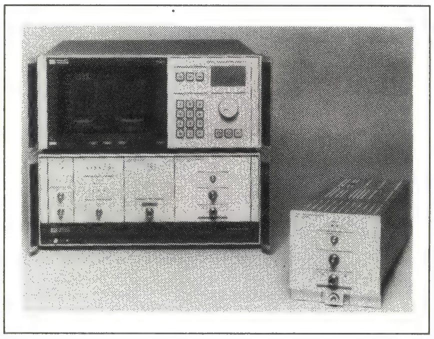
EPROM EMULATOR

- *Substitutes for 2732s to 27512s*
- *Downloads code from IBM PC's or compatible's RS-232C port*

During development and debugging of microcode, you can plug the EE-100 EPROM emulator into your circuit in place of 2732-to-27512 series EPROMs. Adapter cables let you use the emulator in place of 24- or 28-pin devices. For downloading of code, you connect the emulator to the RS-232C port of an IBM PC or compatible computer. The emulator draws no power from your pc board; it has its own separate power supply that allows it to substitute for low-power CMOS EPROMs. $995.

Future Systems Inc, 21634 Lassen St, Chatsworth, CA 91311. Phone (818) 407-1647. FAX 818-407-0681.

Circle No 413



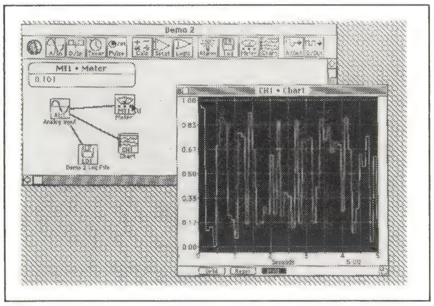
MICROWAVE TEST GEAR

- *Includes two spectrum analyzers and tracking generator*
- *Analyzers have dynamic range to 130 dB at 18 GHz*

The HP 71210XL and 71201XL are high- and mid-performance scalar, microwave spectrum analyzers that handle frequencies to 22 GHz. The HP 70301A is a companion tracking generator that provides a 0.0-dBm leveled output from 2.7 to 18 GHz. At 18 GHz, the high-and mid-performance analyzers' dynamic ranges exceed 130 and 100 dB, respectively. The analyzers feature many automated measurement modes. One such mode allows storing the characteristics of a "golden" reference device, and establishing go/no-go test limits with respect to these characteristics. 71210XL, $91,980; 71201XL, $75,920; 70301A, $25,000. Delivery, 16 weeks ARO.

Hewlett-Packard Co, 19310 Pruneridge Ave, Cupertino, CA 95014. Phone (800) 752-0900.

Circle No 414



IEEE-488 SOFTWARE

- *Runs on Apple Macintosh family*
- *Uses graphic interface to define custom applications*

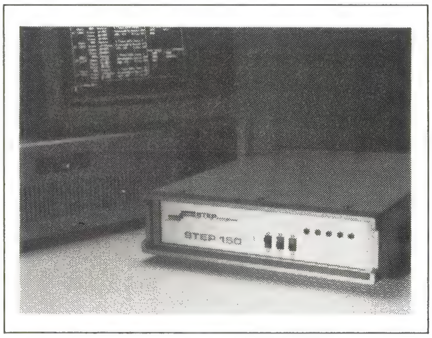
The Analog Connection Workbench version 3.0 is a software package for controlling and acquiring data from IEEE-488 instruments. The software runs on Apple Computer's Macintosh family of personal computers. With little software-operation training, you can develop custom data-acquisition applications by using the Macintosh's mouse to construct block diagrams on the computer's screen. The diagrams use predefined blocks from a library; for example, the blocks define mathematical operations the software will perform. You can create custom icons for functions that you define. In addition, by double clicking on an IEEE-488 icon, you can open a dialog box that lets you define instrument parameters. $995.

Strawberry Tree Computers Inc, 160 S Wolfe Rd, Sunnyvale, CA 94086. Phone (408) 736-1041. TWX 650-317-2834.

Circle No 415

μP DEBUGGER

- *Works with embedded, real-time software*
- *Captures system data and μP-bus data*



The Step-150 Mobile Microcontroller/Microprocessor Measurement Machine (M5) debugs embedded software in real-time control systems. The M5 combines nonintrusive data capture and display with software execution and analysis tools; it captures system-level data and simultaneously records data from the target μP's bus. The unit provides multilevel triggering, a range of storage filters, definable match words, and else/if control statements. You can debug at the object- or source-code level using either assembly language or high-level compiled languages. An unat-

tended mode allows you to set up the unit using an external IBM PC and then detach the PC; internal batteries enable the unit to retain the setup data. $18,500.

Step Engineering Inc, 661 E Arques Ave, Sunnyvale, CA 94086. Phone (408) 733-7837.

Circle No 416

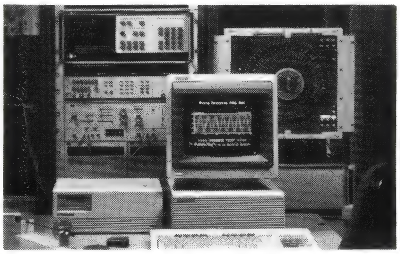
WAVEFORM EDITOR

- *Allows off-line generation of digital patterns*
- *Supports word generation and timing simulation*

Waveform Editor Application Software allows users of the vendor's RS-690 digital word generator to develop data patterns for the generator off line. The software supports the generator's word-generation mode, in which the unit produces a bit during each clock cycle; it also supports the timing simulation mode, in which you can program a line's output state for variable periods. The software, which runs under MS DOS 2.0 or higher, presents you with menus that resemble those that appear on the generator itself. $500. Delivery, four to six weeks ARO.

Interface Technology, 2100 E Alosta Ave, Glendora, CA 91740. Phone (818) 914-2741. FAX 818-335-8346.

Circle No 417



CONTROLLERS

- *Intended for instrument control*
- *Available in desktop and rack-mounted versions*

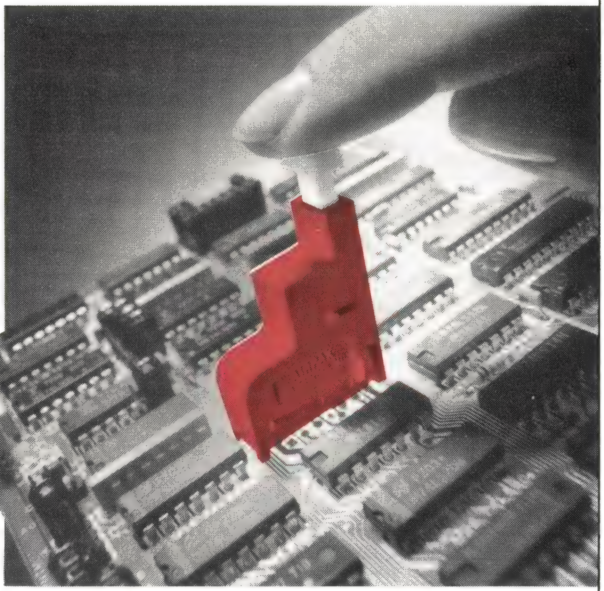
The HP 9000 Models 332 and R/332 instrument controllers are for desktop use and for mounting in equipment racks. The controllers offer a 4× improvement in performance/price ratio compared with the vendor's model 310. They use a 68030 CPU chip operating at 16.67 MHz and accommodate a 68882 arithmetic coprocessor. RAM is mounted on daughter boards that plug onto the mother board and allow you to equip the controllers with 8M bytes of RAM. Standard equipment includes RS-232C and IEEE-488 ports and a graphics frame buffer that can drive either 512×400- or 1024×768-pixel monochrome displays. The Model R/332 has a 9-in. CRT. Desktop systems feature either 12- or 17-in. displays; a color display is optional. Storage includes

Text continued on pg 266

CARDGARD® 2. The Built-In Circuit Protector You Can Reset.

Overloads can wipe out critical tracks and boards. Fuses provide protection, but only once. And replacing them means costly downtime.

CARDGARD® 2 is circuit protection you can reset. It's a UL recognized trip-free mini-breaker. With current ratings of 1 to 6 amps; voltage ratings of 50VDC, 250VAC. It's wave solderable, meets IEC spacing requirements and mounts right on the board. If an overload hits, just pull the board and push the reset. You're done. And, as you can see, CARDGARD® 2 is easy to spot.



Put your finger on CARDGARD® 2. Contact: Airpax Corporation, Cambridge Division, Woods Road, Cambridge, MD 21613. (301) 228-4600. Telex: 6849138, Fax: (301) 228-8910. A North American Philips Company.

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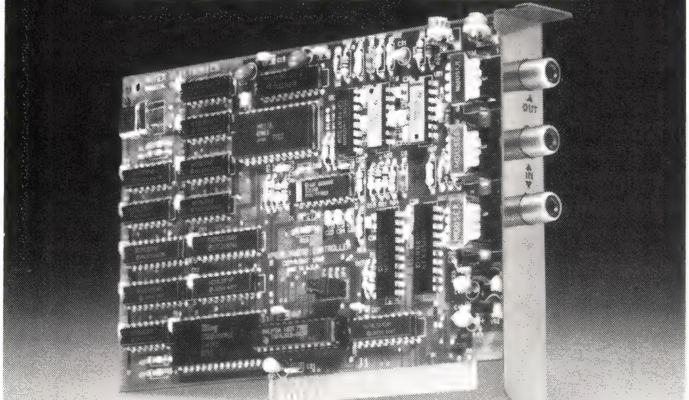
CIRCLE NO 43

AUDIO MIX



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CIRCLE NO 45

a 40M-byte hard disk. The operator interface can use a touch-sensitive screen. Desktop systems, from $6080; rack-mounted systems, from $9900.

Hewlett-Packard Co, 19310 Pruneridge Ave, Cupertino, CA 95014. Phone (800) 752-0900.

Circle No 418

REFLECTOMETER

- *Provides 200-km range*
- *Allows off-line data analysis on laptop PC*

The Model 3200 optical time-domain reflectometer (OTDR) offers a range of 200 km and a dynamic range of 32 dB. The vendor claims it is the first instrument with a dynamic range exceeding 30 dB. You can use it for measurements on fiber-optic links that operate in both single and multiple modes and for those that use the light of two wavelengths. The PC3110 data logger, a companion to the instrument, automatically calculates bidirectional splice losses. The unit is based on an IBM PC-compatible laptop computer and proprietary OTDR-emulation software. It can store 70 complete fiber signatures with setup information and splice locations on a 3½-in. diskette. $22,500 to $35,000. Delivery, six weeks ARO.

Photon Kinetics Inc, 4900 SW Griffith Dr, Suite 150, Beaverton, OR 97005. Phone (503) 644-1960. TLX 4992356.

Circle No 419

PC TESTER

- *Performs power-on diagnostic self tests*
- *Allows troubleshooting of PCs that won't load DOS*

The Postcard is a half-length card that plugs into the IBM PC bus and performs a series of power-on self-test routines that pinpoint problems in "dead" PCs—even in ones that won't load the DOS. One of the routines is a burn-in loop that runs continuously to locate intermittent problems. The card works in IBM PCs, PC/XTs, PC/ATs, PS/2 Model 30, PS/2 Model 30 286, and 80386-based systems. It is compatible with the vendor's Modular BIOS (basic input/output system) and the BIOS of another vendor. Extended diagnostics test a computer's base memory, video functions, rigid and flexible disk drives, parallel and serial ports, keyboard, math coprocessor, and extended memory. $399.

Award Software Inc, 130 Knowles Dr, Los Gatos, CA 95030. Phone (408) 370-7979. FAX 408-370-3399.

Circle No 420

Understanding the European telecommunications industry

European Telecommunication Organisations is a study that provides basic telecommunications-industry information about 10 European countries in anticipation of the completion of the European market in 1992. Conducted under a grant from the European Commission's FAST program, the Anglo-German Foundation, Alcatel NV, and the German Ministry of Technology, the study includes an introductory chapter that presents the structure, functioning, and evolution of European telecommunications systems. In section 1, an expert from each country discusses regulatory bodies, the extent of the national carrier's monopoly, and the relationship between the carrier and the national telecommunications manufacturing industry. The second section attempts to analyze the effects of the current institutional arrangements. Finally, the third section comments on probable regulatory and institutional changes. The document includes a glossary of technical terms.

Nomos, Box 610, 7570 Baden-Baden, West Germany.

Circle No 425

Reference surveys time and frequency systems

The *Austron Timing Reference Handbook* is an illustrated guide for studying and designing timing systems. After outlining a brief history of time measurements, the 172-pg publication describes the most recent technological developments in timing systems and gives application examples. The handbook provides data sheets for all the vendor's product lines, including time-code instruments, time and frequency instruments, and oscillators.

Austron Inc, Box 14766, Austin, TX 78761.

Circle No 426

Synchro handbook

The Synchro Conversion Handbook provides both a practical tutorial and a reference source for designers, systems engineers, and systems users who are involved with

synchro products. The publication presents synchro-conversion techniques, data sheets, and a range of topics from the fundamentals of angle-sensing transducers to design constraints and selection criteria for typical applications. In addition, the book explores not only the company's approach to synchro conversion but also other generally accepted techniques. Charts, diagrams, and tables supplement the text.

ILC Data Device Corp, 105 Wilbur Pl, Bohemia, NY 11716.

Circle No 427

Catalog for LAN users

NetConnect is a 48-pg direct-mail catalog that features more than 500 computer networking products for LAN users. The 4-color publication provides product diagrams, illustrations, and cross-reference charts (where appropriate) to ensure customers that the products they order will connect with their intended peripherals. The catalog also provides useful hints, such as comparing the merits of twisted-pair with fiber-optic cabling, or Ethernet with token-ring networks.

Inmac, Box 58031, Santa Clara, CA 95052.

Circle No 428

Information service for Unix systems

Reports on Unix Systems & Software is a complete information service covering products, issues, and standards for the Unix operating system. The service includes information about three standards: Posix, ISO/OSI (International Organization for Standardization/Open Systems Interconnection), and US Government Applications Portability Profile (APP). The reports also cover software portability/multivendor networking, Unix facilities and tools, Unix System V and competitive implementations, and vendor-specific implementa-

tions. The service is updated monthly and publishes a newsletter that provides an analysis of new developments and issues concerning Unix, user assessments of different systems, product-comparison tables, and a buyer's guide.

Datapro Research, 1805 Underwood Blvd, Delran, NJ 08075.

Circle No 429

Booklet on technology of polymer thick film

The 38-pg booklet entitled *"PTF," A Review of Polymer Thick Film Technology* begins with a historical and technical overview. It emphasizes that PTF materials and processes should not be regarded as a separate and distinct technology but should be used in a supportive role in relation to printed-circuit etched-copper and thick-film cermet technologies. Thus, the booklet advocates the combination of various interconnection technologies to meet the demands of rapidly developing microelectronic assemblies.

Patintel, 14 Woodlands, Gosforth, Newcastle upon Tyne, NE3 4YL, UK.

INQUIRE DIRECT

Update on device modeling

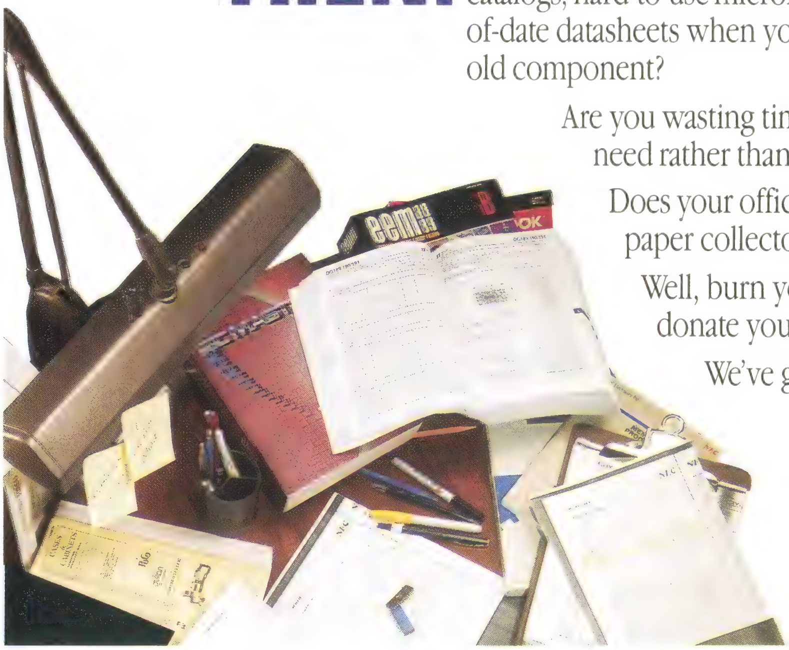
The version 1.1 report on automated device characterization and modeling (ADCM) is a 300-pg update to the version 1.0 ADCM report. The report serves as a product-selection guide and reviews current trends in the field of CAE tools and systems used in semiconductor electrical test and characterization, statistical process control, and device modeling for Spice simulation at the board level and the IC level. Version 1.1 includes two volumes: *Commercial Parametric Test Systems and Data Acquisition Software* and *SPICE Model Parameter Extraction Software.* The publications are based primarily on the authors' experience and extensive vendor interviews, complemented by reviews of product documentation and related publications. First-time purchasers: each volume, $1300; set, $2400; version 1.0 owners can purchase each volume for $395.

Mosec, 10212 Parlett Pl, Cupertino, CA 95014.

INQUIRE DIRECT

Two training videos for graphics

These two instructional video programs, #D14 *AutoCAD Release 10: For the Beginner* and #D15 *AutoCAD Release 10: Advanced Operations*, provide the materials for self-instruction at the beginning



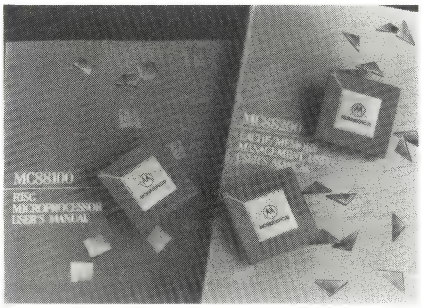
and advanced levels. The elementary level focuses on the display features and 3-D graphics capabilities of Release 10, and it compares the viewing capabilities of the User Coordinate System with the World Coordinate System. The advanced program also explores 3-D graphics capabilities and introduces Lisp programming and some of Lisp's special features. Both programs include a study guide. $299 each.

Bergwall Productions Inc, Box 238, Garden City, NY 11530.

Circle No 430

User's manuals for RISC μP family

These two user's manuals provide technical information about the vendor's 88100 CPU and 88200 cache/memory-management unit, which are part of the vendor's 88000 RISC (reduced-instruction-set computer) μP family. The two publications serve as references for system designers and software developers. They feature explanations of the addressing modes and instruction sets, analyses of bus operations and register usage, data about electrical characteristics, and outlines of minimum system configurations. $2.65 each.



Motorola Inc, Literature Distribution Center, Box 20912, Phoenix, AZ 85036.

INQUIRE DIRECT

Guide helps you select digital multimeters

This 4-color, illustrated leaflet describes the company's latest line of heavy-duty digital multimeters. The publication features the HD150 Series of 3½-digit, autoranging DMMs and is free to qualified specifiers.

Beckman Industrial Corp, 3883 Ruffin Rd, San Diego, CA 92123.

Circle No 431

Data sheet explains synchro/resolver converter

This data sheet deals with the company's HSRD1056RH synchro-/resolver-to-digital converter. The 4-pg publication describes the converter and presents its specifications, features, and applications.

Natel Engineering Co Inc, 4550 Runway St, Simi Valley, CA 93063.

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CIRCLE NO 325

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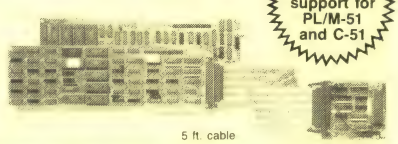
" The Best 8051 Emulator"

NEW Source Level support for PL/M-51 and C-51



8051

See EEM 88/89 Page D-1304

PC based emulators for the 8051 family
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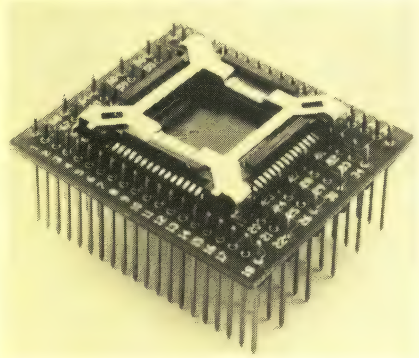

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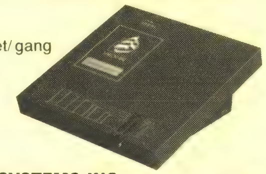
Sailor-2, Sailor-8: set/gang high speed EPROM programmers. $545– $1995.



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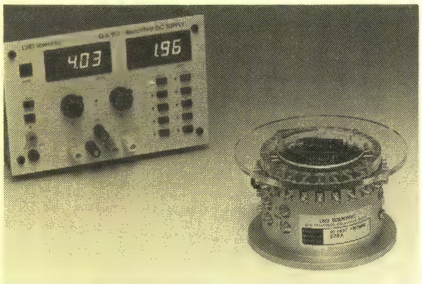

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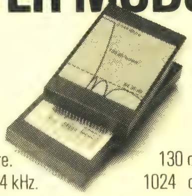

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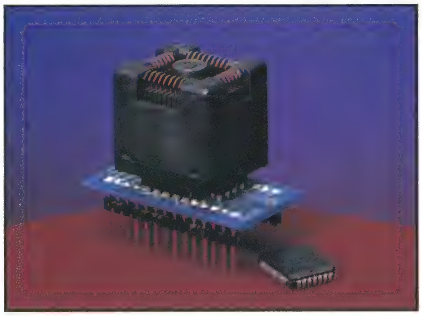

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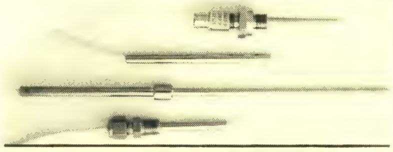

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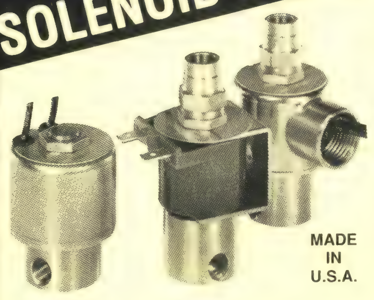

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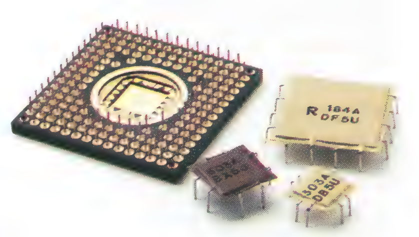

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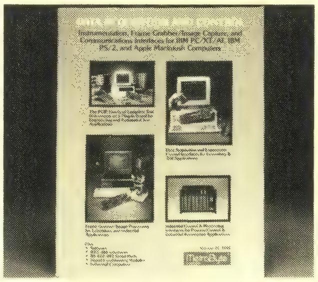

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CIRCLE NO 344

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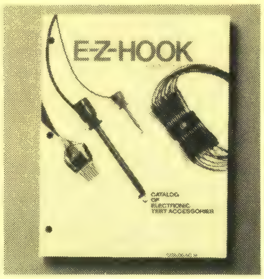

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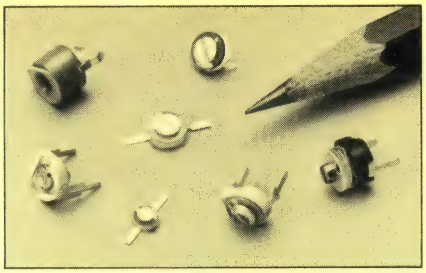

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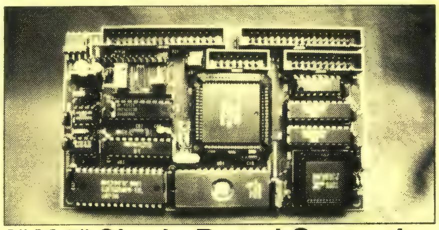

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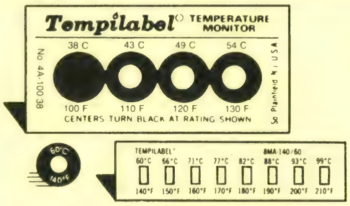

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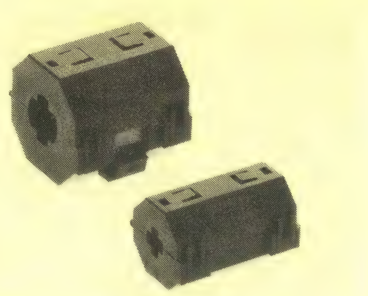

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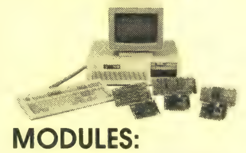

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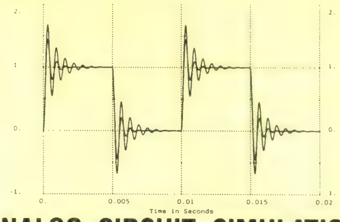

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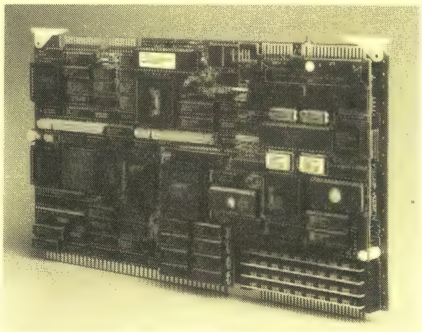

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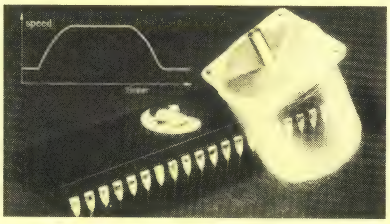

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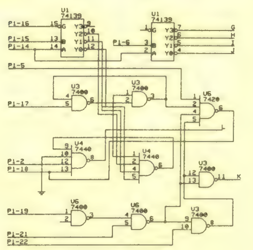

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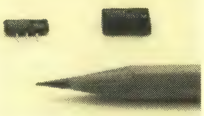

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FDC 1005	FDR 1005		1 0ns± 0 10ns	300ps or Less	800MHz or More
FDC 1505	FDR 1505		1.5ns± 0.15ns	400ps or Less	550MHz or More
FDC 2005	FDR 2005		2.0ns± 0.20ns	400ps or Less	550MHz or More
FDC 2505	FDR 2505		2.5ns± 0.20ns	500ps or Less	450MHz or More
FDC 3005	FDR 3005		3 0ns± 0 20ns	500ps or Less	450MHz or More
FDC 3505	FDR 3505		3 5ns± 0 25ns	600ps or Less	400MHz or More
FDC 4005	FDR 4005		4 0ns± 0 30ns	700ps or Less	350MHz or More
FDC 4505	FDR 4505		4.5ns± 0.30ns	700ps or Less	350MHz or More
FDC 5005	FDR 5005		5.0ns± 0.30ns	700ps or Less	350MHz or More
FDC 0510	FDR 0510	100Ω ± 10%	0.5ns± 0.10ns	300ps or Less	800MHz or More
FDC 1010	FDR 1010		1.0ns± 0.10ns	300ps or Less	800MHz or More
FDC 1510	FDR 1510		1.5ns± 0.15ns	400ps or Less	550MHz or More
FDC 2010	FDR 2010		2.0ns± 0.20ns	400ps or Less	550MHz or More
FDC 2510	FDR 2510		2.5ns± 0.20ns	500ps or Less	450MHz or More
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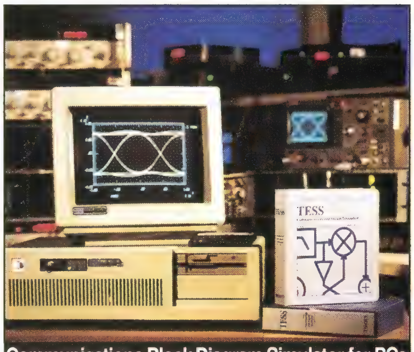

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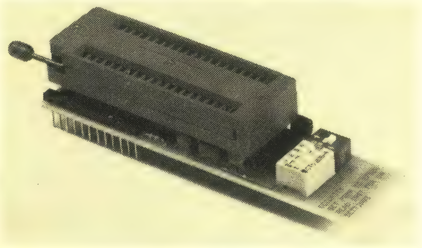

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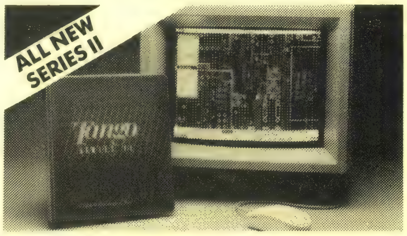

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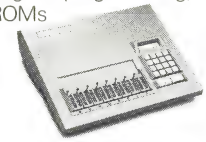

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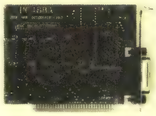

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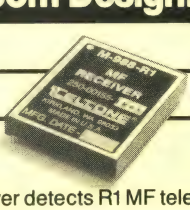

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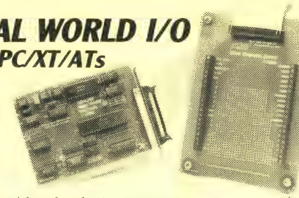

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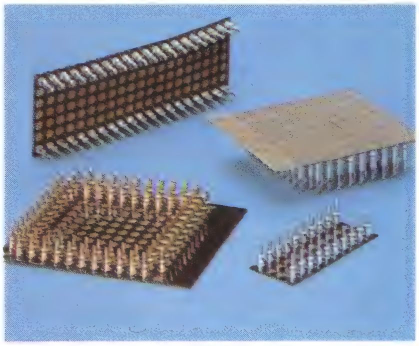

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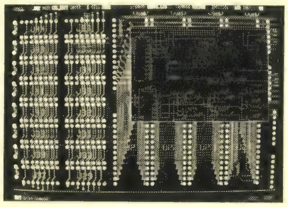

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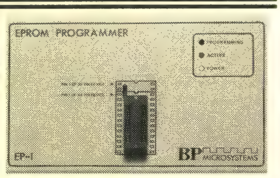

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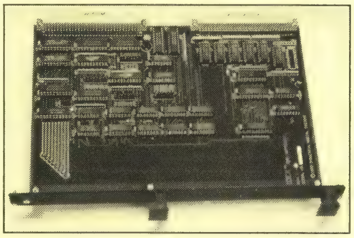

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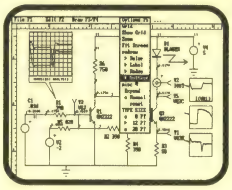

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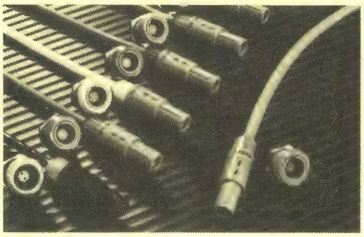

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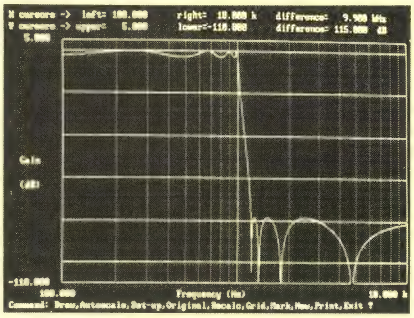

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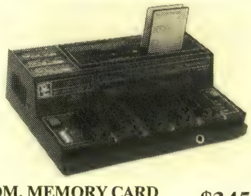

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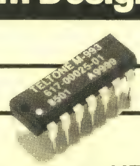

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July 6	June 15	Product Showcase — Volume I, Power Supplies	Closing: June 22 Mailing: July 13
July 20	June 29	Product Showcase — Volume II, Components	Closing: July 21 Mailing: Aug. 10
Aug. 3	July 13	Integrated Circuits, Computer Boards	
Aug. 17	July 27	Military Electronics Special Issue Military Software	Closing: Aug. 4 Mailing: Aug. 24
Sept. 1	Aug. 10	Test & Measurement, Integrated Circuits	Closing: Aug. 18 Mailing: Sept. 7
Sept. 14	Aug. 24	Industrial Product Showcase, Digital ICs	Closing: Aug. 30 Mailing: Sept. 21
Sept. 28	Sept. 7	Integrated Circuits, Computer Peripherals	Closing: Sept. 15 Mailing: Oct. 5
Oct. 12	Sept. 21	DSP Chip Directory, Integrated Circuits	Closing: Sept. 28 Mailing: Oct. 19
Oct. 26	Oct. 5	Test & Measurement Special Issue Computers & Peripherals	Closing: Oct. 27 Mailing: Nov. 16
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EDN covers new and developing technologies to inform its readers of practical design matters that will be of concern to them at once or in the near future.

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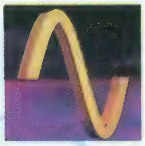

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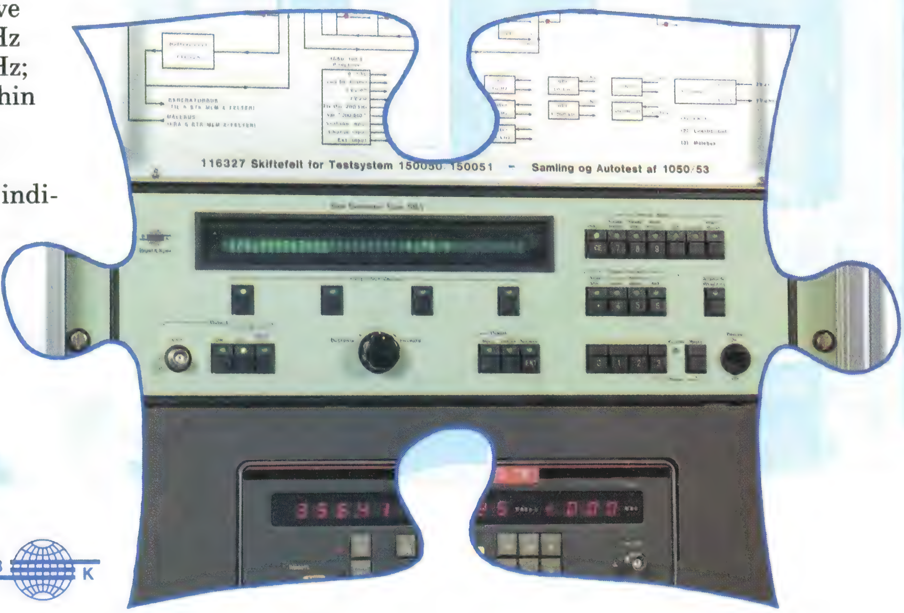

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"When I was on the client side, I demanded sales results from my advertising dollars," says John Poturny, President of Poturny & Associates. "Today I'm on the agency side, and I expect the same for my clients — advertising that generates sales."

Advertising results. A publication must provide them.

"After running ads in EDN News Edition, our phones ring and proposal activity soars immediately for our military power supplies," says Fred Silver, Director of Marketing at Rantec, a division of Emerson Electric.

Advertising results. For Poturny & Associates and Rantec, EDN News Edition gets them.

"We traced prototype orders worth $2 million in sales to a lead generated by our ad in EDN News Edition," said Silver.

Both Silver and Poturny agree about the power of EDN News Edition, "it gets results."

John Poturny

Fred Silver

EDN News Edition works for marketing communication partners, Poturny & Associates and Rantec. It can work for you.

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Where Advertising Works

"EDN'S MAGAZINE AND NEWS EDITIONS ADDRESS THE WORLDWIDE LINEAR IC MARKET WE'RE AFTER."

Bill Ehrsam
Vice President of Marketing
Linear Technology Corporation

"When I buy EDN's Magazine and News Editions, I'm buying a powerful worldwide circulation and the most prestigious editorial environments available. That's a combination that gets results," says Bill Ehrsam, Vice President of Marketing for Linear Technology Corporation.

Ehrsam knows industry sales for high-performance linear ICs are split between the United States, Western Europe, and the Pacific Rim. Says Ehrsam, "It's my job to choose media that mirrors the world markets."

For complete global coverage, Ehrsam places his advertising in EDN Magazine Edition and EDN News Edition. "Linear Technology Corporation is a strong supporter of EDN Magazine Edition. We rely on EDN's targeted coverage of the U.S. and Western Europe. When EDN News Edition added Pacific Rim circulation in December 1987, we added it to our media schedule."

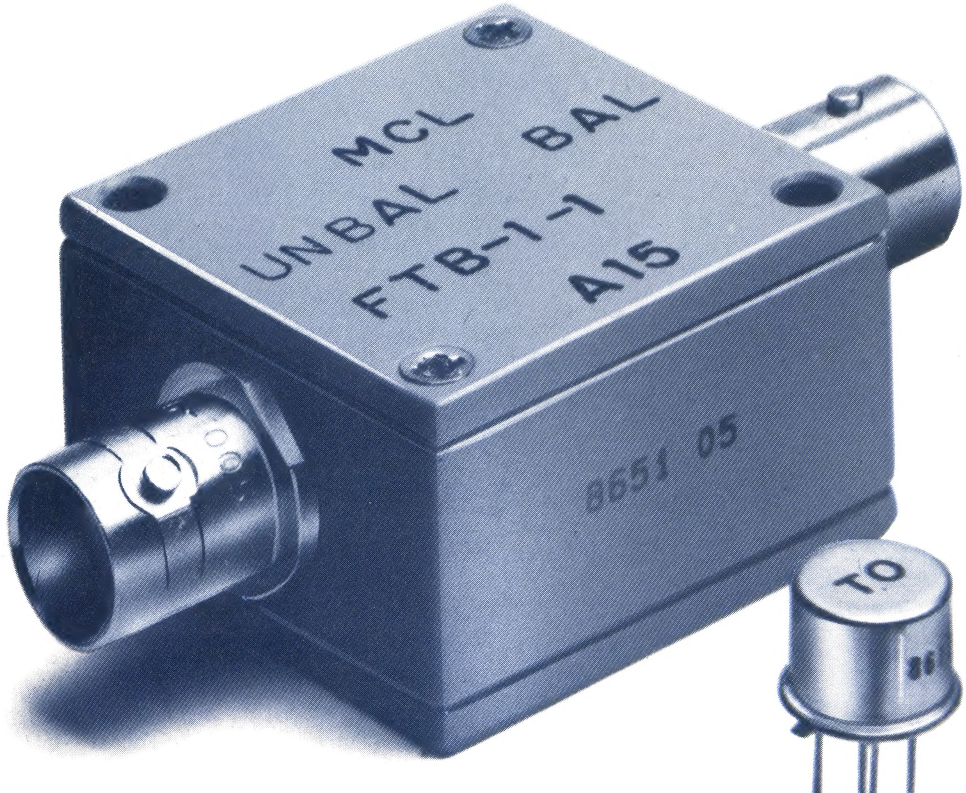
For Bill Ehrsam, "EDN's Magazine and News Editions form the cornerstone for Linear Technology Corporation's media plan now and in the future."

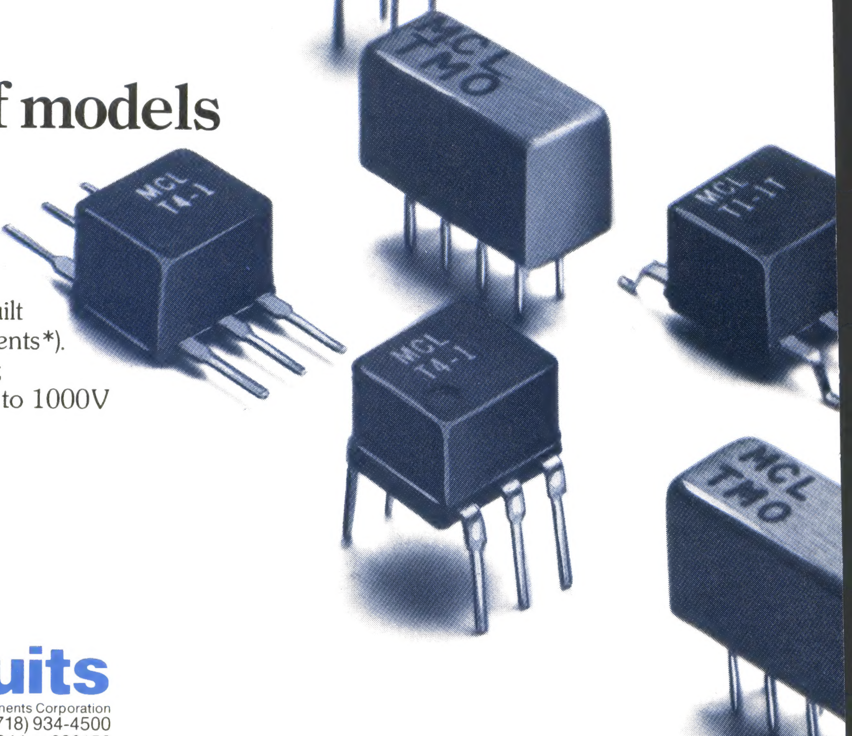
Advertising in EDN Magazine and News Editions works for Linear Technology Corporation. It can work for you.

EDN

Where Advertising Works

RF transformers





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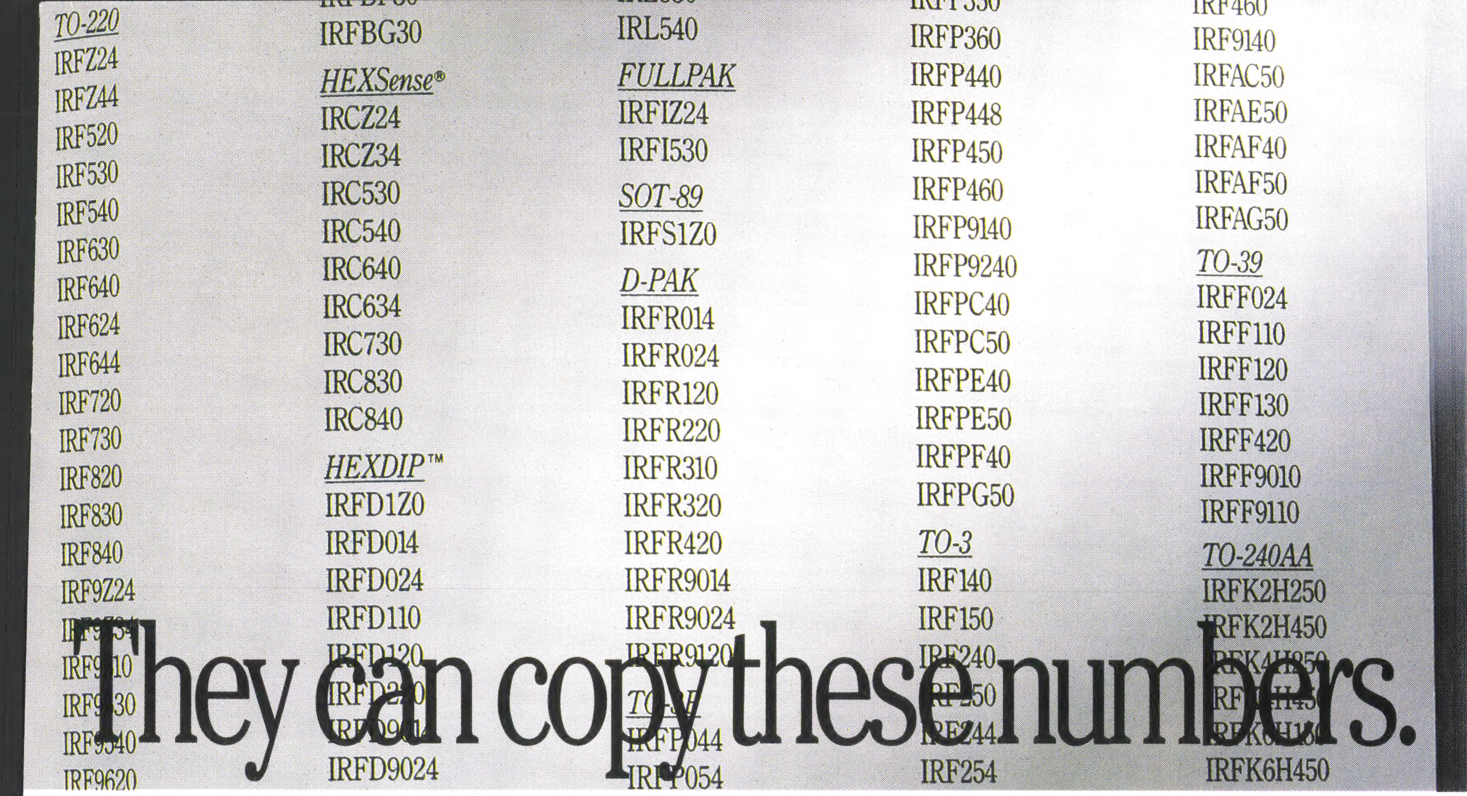

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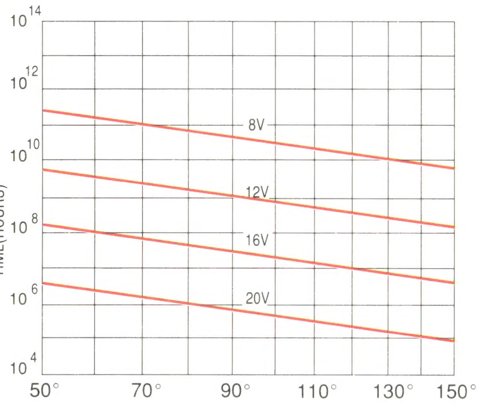

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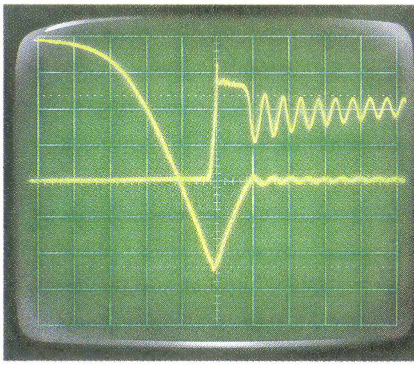
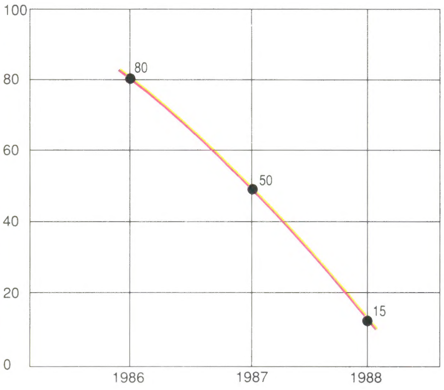


HEXFET IRF530 under avalanche



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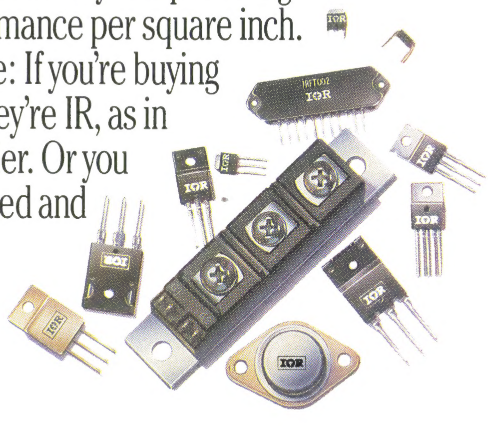

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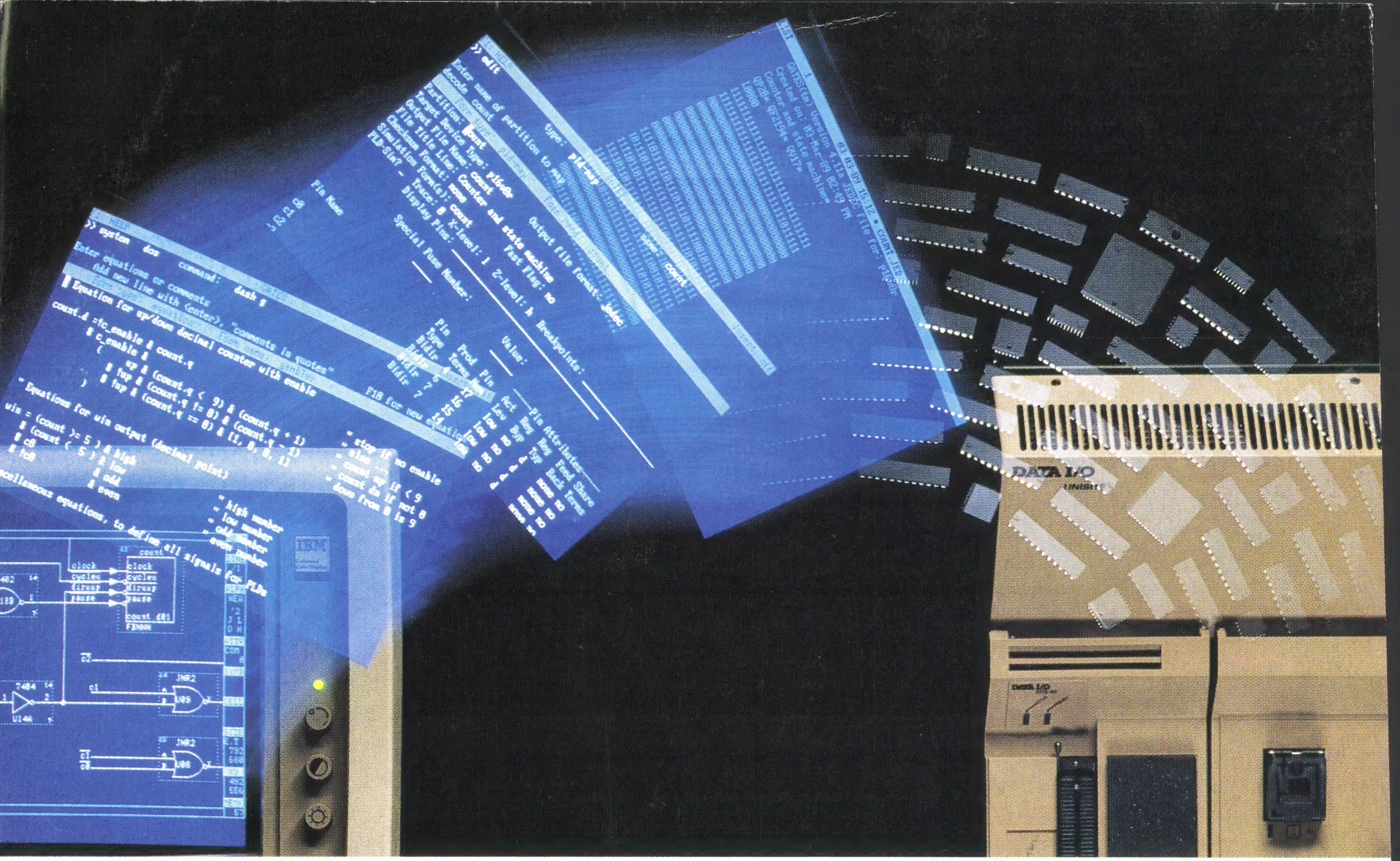

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